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Groundwater Quality Monitoring of Western Coal Strip Mining: Identification and Priority Ranking of Potential Pollution Sources

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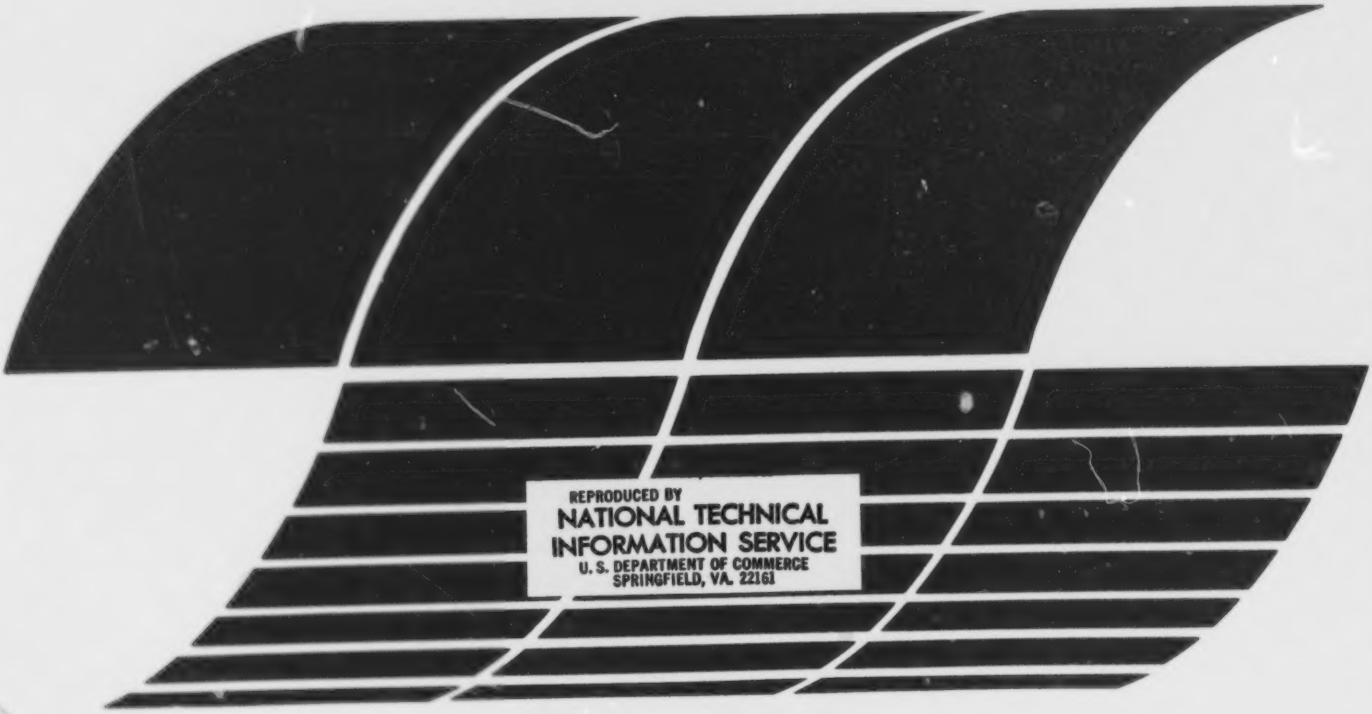

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16. ABSTRACT This report is the first in a series of several to come out of a 5-year study to assess the impact on groundwater quality of coal strip mining in the Western United States. Presented is a preliminary priority ranking of potential sources of groundwater pollution in an area within Campbell County, Wyoming, overlying one of the major coal fields in the Powder River Basin.

The priority ranking was developed by making a thorough review of the existing data available from monitoring activities of mining companies and various county, State, and Federal agencies. Potential pollution sources and methods of waste disposal at seven operating mines and also in the vicinity of the City of Gillette were inventoried. The data were carefully reviewed to identify the potential pollutants associated with each source. Groundwater usage was inventoried. An appraisal of the hydrogeologic framework and existing groundwater quality was developed. By superimposing the identified potential groundwater pollution sources on the hydrogeologic framework and making estimates of pollutant mobilities from these sources, the preliminary priority ranking was developed. The study has revealed a major data and information gap in the understanding of pollutant mobilities and, thus, the priority ranking presented will likely undergo considerable revision as the program progresses. This report was submitted in partial fulfillment of Contract #68-03-2449 by General Electric—TEMPO, Center for Advanced Studies, under the sponsorship of the U.S. Environmental Protection Agency.

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GROUNDWATER QUALITY MONITORING OF WESTERN COAL STRIP MINING:

Identification and Priority Ranking of Potential Pollution Sources

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FOREWORD

Protection of the environment requires effective regulatory actions which are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interactions, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach which transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory—Las Vegas contributes to the formation and enhancement of a sound monitoring data base for exposure assessment through programs designed to:

- Develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- Demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs.

This report presents the initial phases of a study to design and implement groundwater quality monitoring programs for Western coal strip mining. The development of a preliminary priority ranking of potential pollution sources and the pollutants associated with these sources is presented.

The results of this report are the initial segment of the design and field implementation effort. The priority ranking will be combined in subsequent study phases with evaluations of deficiencies in existing or proposed monitoring efforts and alternative monitoring technologies to design a cost-effective groundwater quality monitoring program.

The research program, of which this report is part, is intended to provide basic technical information and a planning format for the design of groundwater quality monitoring programs for Western coal strip mining operations. As such, the study results may be used by coal developers and their consultants, as well as the various local, State, and Federal agencies with responsibilities in environmental monitoring and planning.

Further information on this study and the subject of groundwater quality monitoring in general can be obtained by contacting the Monitoring Systems Design and Analysis Staff, Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Las Vegas, Nevada.

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PREFACE

General Electric—TEMPO, Center for Advanced Studies, is conducting a 5-year program dealing with the design and implementation of an exemplary groundwater quality monitoring program for Western coal strip mining. The coal strip mining activity discussed in this report is located in Campbell County, Wyoming. In addition to mining impacts, the report discusses secondary water resource impacts of municipal and industrial support programs which accompany the mining effort. The report follows a stepwise monitoring methodology developed by TEMPO.

This report represents the initial phase of this research program. Described herein is the development of a preliminary priority ranking of potential pollution sources and their associated pollutants. This priority ranking will be utilized in subsequent phases of the research as the basis for defining monitoring needs and for ultimately designing the monitoring program.

In the next phases of this research program, a preliminary monitoring design is to be developed and implemented in the field. Initial field study results may result in a reevaluation of the priority ranking presented in this report. The final product of the 5-year program will be a planning document which will provide a technical basis and a methodology for the design of groundwater quality monitoring programs for coal development companies and the various governmental agencies concerned with environmental planning and protection.

SUMMARY

General Electric—TEMPO has developed a methodology for designing groundwater quality monitoring programs. This was a conceptual design which involved a series of data compilations and evaluation steps leading to a monitoring system in place. General Electric—TEMPO is now applying that methodology to design a system to monitor the impact of western coal strip mining on groundwater quality. This document reports the field survey and literature research performed during the first phase of the design process. The goal of this phase is to identify and rank the major sources of groundwater quality degradation. The site for which the monitoring system is being designed follows the outcrop of the Fort Union Formation in Campbell County, Wyoming. In addition to the City of Gillette, Wyoming, the project area includes the following mines: Carter North Rawhide, AMAX Eagle Butte, Wyodak, AMAX Belle Ayr, Sun Oil Cordero, Kerr-McGee Jacobs Ranch, and ARCO Black Thunder.

The priority ranking is based on a sequence of data compilation and evaluation steps. These steps include identification of potential pollution sources, methods of waste disposal, and potential pollutants associated with the various waste sources; and an assessment of the potential for infiltration and subsequent mobility of these pollutants in the subsurface. The three basic criteria used to develop the source-pollutant ranking are:

- Mass of waste, persistence, toxicity, and concentration
- Potential mobility
- Known or anticipated harm to water use.

The information base and related assessments utilized to develop rankings based on the above methodology are summarized in the main body of this report.

Available background information and field reconnaissance were employed to describe the hydrogeology and water quality of the study area. These data were used in concert with the source-pollutant characterization to assess the potential for pollutant mobility.

Three major classifications of potential pollution sources have been inventoried: Agricultural, Industrial, and Municipal. Agricultural sources were found to be insignificant due to their diffuse nature. Irrigated farmland is practically nonexistent and dryland farming, which is economically marginal, is the general method.

The Industrial classification includes Construction, Oil and Gas

Extraction, Coal Strip Mining, and Coal Conversion activities. Of these four, coal strip mining and coal conversion are the most significant in terms of potential groundwater quality degradation. Almost all of the wastes associated with the construction industry are either disposed of in the Gillette landfill, and as a result come under the Municipal wastes category, or are disposed of with mine solid wastes on the leases. The same can be said for sanitary wastes from the construction industry where the City or mine disposal facilities are utilized.

The oil and gas extraction industry is probably a major potential groundwater pollution source, however, it will not be investigated in a regional sense in this study. On mine leases where oil and gas wells exist or have existed, potential groundwater impacts are of minor concern since they are few in number and closely scrutinized because of their proximity to the mining operations.

Coal strip mining and its related sources have considerable potential to produce groundwater quality degradation. On the majority of mines, pollutant source-specific monitoring does not eixst. Where monitoring of sources has been conducted it has not been source oriented but directed toward assessing background quality levels, with the hope that eventually any changes in quality due to pollutants will show up in the monitoring program.

The above approach is the traditional approach utilized, but it is contrary to the objectives of Public Laws 92-500 and 93-523, which are aimed at preventing, reducing, and eliminating groundwater quality degradation. Once pollutants show up in a background quality monitoring system, in many cases, it is too late to institute controls. Source monitoring is the key to determining which controls to implement and whether they are working.

For active mining, the pit discharge represents a potential source of groundwater pollution. Much of the pit discharge is derived from native groundwater; however, explosives, sewage effluents, spoils, coal, and other sources can contribute pollutants.

The relocation of spoils produces a changing chemical environment that will be a permanent potential source. Some groundwater will likely always be in contact with the lower parts of the emplaced spoils. Also, some streamflow will generally be rerouted, after mining, over the spoils along the former floodplains and percolation will occur in some areas. Holding ponds placed on the spoils would be transitory in nature. Groundwater contacting the spoils will tend to occur indefinitely in specific parts of the reclaimed areas. In any area where groundwater was present in or above the coal seam prior to mining, the spoils will generally be in contact with groundwater after mining ceases. Spoils placed below the water table have top priority among mining sources for the following reasons:

- The soil and vadose zone are bypassed; thus there is no pollutant attenuation in these zones

- Generally, materials with the highest pollution potential are placed at the bottom of the spoils, and it is this area that will be contacted by groundwater

- This source is permanent in a sense and can contribute pollutants over decades or centuries.

Another priority for mining sources would be for rerouted surface water percolating into the spoils. The extent of this problem depends largely on the chemical nature and hydraulic head ultimately established in the spoils and underlying materials and the permeability of spoils beneath the stream channel. This source will also be permanent and can contribute pollutants for many decades or centuries after mining ceases. A third priority for mining sources would be percolation of streamflow below points of pit discharge. The extent of this problem is presently poorly known due to a lack of adequate monitoring of pit discharge. Dilution due to mixing with surface water from natural runoff would limit the potential groundwater pollution.

The quality of surface water can also be adversely impacted because in some parts of the leases the groundwater contributes to surface water flow. Over the long term, substantial increases in the salinity of surface water could occur. This, in turn, could exert profound adverse impacts on downstream users of surface water.

Of the three coal conversion activities projected to be implemented in the project area, steam electric power generation, gasification, and liquification, only steam electric power generation is being implemented on a large scale. This plant is located on the Wyodak lease and most of its waste products will be disposed of in the mine pits. The primary waste will be fly ash, which will be disposed of both in ponds and as landfill. Secondary wastes, e.g., sewage effluent and sludge, will also be disposed of in ponds or as landfill.

Top priority should be given to fly ash landfill disposal in the pit at levels which will lie below groundwater level. This top priority is based on:

- The disposal is basically permanent, and pollutants can be produced for decades or centuries

- Certain trace elements may well qualify fly ash as a hazardous waste

- The soil and vadose zone are bypassed and thus pollutant attenuation in these zones will not occur

- Large volumes of fly ash will be disposed of.

Second priority should be given to the fly ash slurry pond. This priority is based on:

- The wastewater disposed to this pond presents a ready source of water for leaching pollutants to the groundwater

- This source contains a variety of pollutants, including salinity from brine disposal and metals from the fly ash.

Third priority should be given to fly ash landfilled above the water table and beneath rerouted streams. This priority is based on:

- A ready source of water is available for leaching
- The fly ash may well qualify as a hazardous waste.

The principal potential municipal sources of groundwater pollution are the landfill, sewage treatment plant, and water treatment plant. Only limited monitoring has been done on the landfill, sewage treatment plant, or water treatment plant. Individual wells within the City's well field are subject to damage from any of these three sources and, in the long term, from the mining operations.

The complete priority ranking is shown in Table 1. A great deal of effort has been expended on the study of the hydrogeology of the study area and a large amount of research has been conducted on coal strip mine development and environmental effects. However, significant information voids exist with regard to potential pollutant characterization and the mobility of these materials in the hydrosphere. Hence, professional judgment plays a large role in proposing this preliminary source-pollutant ranking.

This ranking will serve as the basis for the design of a monitoring plan for western coal strip mine development. The next phase of the design program includes evaluation of existing monitoring programs, identification of alternative monitoring approaches to address the source-pollutant ranking, and selection of a monitoring program for field implementation. This implementation will be used to verify (and quite probably revise) the preliminary ranking provided here.

TABLE 1. PROJECT AREA POTENTIAL POLLUTION SOURCE PRIORITY RANKING BY MAJOR CATEGORY

Coal strip mining	Coal conversion	Municipal
1. Spoils (below water table)	1. Fly ash (below water table)	1. Hazardous wastes at landfill
2. Spoils (above water table below ponds or streams)	2. Fly ash slurry pond	2. Disposal well water treatment plant
3. Pit discharge (to streams)	3. Fly ash solids (above water table)	3. Oily waste ponds at landfill
		4. Garbage trench at landfill
		5. Sewage effluent to Donkey Creek

CONTENTS

Foreword iii
Preface v
Summary vi
Figures xiii
Tables xvi
List of Abbreviations xx
Acknowledgments xxii
Section
1 Introduction 1
  Criteria for selecting the monitoring area 2
  Selection of the project area 3
  Implementation of the priority ranking scheme 5

2 Potential Sources of Pollution and Methods of Disposal 7
  Agriculture 7
  Industry 8
  Oil and gas extraction 15
  Construction 15
  Coal conversion 18
  Municipal sources of pollution 24

3 Potential Pollutants 30
  Agriculture 30
  Coal strip mining 30
  Oil and gas extraction 54
  Construction 54
  Coal conversion 56
  Municipal 62

4 Groundwater Usage 74
  Municipal usage 74
  Rural domestic usage 75
  Industrial usage 76
  Agricultural usage 77

5 Hydrogeologic Framework 78
  Surface water hydrology 78
  Soils 94
  Geology 106
  Hydrogeology 110
  Modified hydrogeology 155

6 Existing Groundwater Quality 164
  Regional 164
  Municipal 184

7 Infiltration Potential 191
  Coal strip mining 191
  Coal conversion 194
  Municipal sources 194

8 Pollutant Mobility in the Vadose Zone 198
  Coal strip mining 198
  Coal conversion 202
  Municipal 203

9 Pollutant Mobility in the Saturated Zone 214
  Coal strip mining 214
  Coal conversion 216
  Municipal sources 217

10 Priority Ranking of Potential Groundwater Pollution Sources 222
  Agricultural activities 222
  Industrial 222
  Municipal 226

References 229
Appendix A 237

FIGURES

Number		Page
1-1	Major coal fields of Wyoming	4
2-1	Oil and gas fields associated with the Eastern Powder River Basin, Wyoming	16
2-2	Hole bottom locations (Hoe Creek Experiment No. 1)	22
2-3	Comparison of measured and calculated water production rates for the Hoe Creek Experiment No. 1 site	23
2-4	Water levels at several locations within the fracture zone	23
2-5	Plan view of the packed-bed experiment	24
5-1	Watershed map	80
5-2	Physiographic divisions and drainage of Campbell County, Wyo.	81
5-3	Flow duration curves for selected Wyoming streams	84
5-4	Relations for estimating flow characteristics in region 2 by using drainage area	85
5-5	Relations for estimating flow characteristics in region 3 by using drainage area	86
5-6	Hydrologic regions at monitoring area	87
5-7	Surface water quality measurement sites	88
5-8	Block diagram showing positions of some major kinds of aridisols and their associates	99
5-9	Soil associations of Campbell County, Wyoming	100
5-10	Generalized map showing the Powder River Basin in relation to nearby structural features	107
5-11	Correlation of coal beds in the Powder River Coal Basin	109
5-12	Aquifer relationships	111

Number Page

5-13 Plots of results from four pump tests near Belle Ayr Mine 116

5-14 Isopach map of unconsolidated deposits along Caballo Creek 118

5-15 Hydrographs of three wells 119

5-16 Water level fluctuations in well N-3, April 26 - July 1, 1974 120

5-17 Water level fluctuations in well 481, May 10 - July 4, 1974 121

5-18 Geologic cross section from the center of the east line, section 22, to the NE corner, SE¼, NE¼, section 27, T51N, R72W 125

5-19 Geologic cross section along west side of section 21, T51N, R72W 126

5-20 Monthly water level elevations in instrumented monitor wells 130

5-21 Monthly water level elevations in instrumented monitor wells 131

5-22 Potentiometric surface map, ARCO Black Thunder Lease 135

5-23 Groundwater flow in Roland aquifer 136

5-24 Monitor well locations, ARCO Black Thunder Lease 137

5-25 Kerr-McGee Jacobs Ranch mine, Thunder Creek area 145

5-26 Kerr-McGee Jacobs Ranch mine cross section K-K 147

5-27 Static water levels— Jacobs Ranch mine 148

5-28 Static water levels— Jacobs Ranch mine 149

5-29 Kerr-McGee Jacobs Ranch mine well locations 150

5-30 Water levels of monitor holes at Sun Oil Cordero mine 153

5-31 Idealized east-west cross section of Wyodak site 154

5-32 Contours of water table, Wyodak area 156

5-33 Effect of 50 years of mining in Wyodak north pit upon water table 157

5-34 Locations of monitoring wells, Wyodak mine 158

6-1 Groundwater gaging network at the Black Thunder Site 178

Number Page

8-1 Mobility of copper, lead, beryllium, zinc, cadmium, nickel, and mercury through 10 soils series 205

8-2 Mobility of selenium, vanadium, arsenic, and chromium through 10 soils series 205

TABLES

Number		Page
2-1	Other Municipalities	28
3-1	Site-specific Topsoil Characteristics	31
3-2	Concentrations of Trace Elements Boron, Cadmium, Lead, and Mercury in Soils on the Eagle Butte Mine Property	31
3-3	Site-specific Overburden Characteristics	33
3-4	Sulfur and Trace Element Concentrations in Coal Samples	35
3-5	Hypothetical Quality of Wastewater from the Gillette Treatment Plant	37
3-6	Representative Septic Tank Effluent Concentrations and Percent Removed	39
3-7	Aerobic Tank Effluent Concentrations	40
3-8	Range of Chemical Composition of Sanitary Landfill Leachate	43
3-9	A Sample List of Nonradioactive Hazardous Compounds	45
3-10	Chemical Analysis of Incinerator Fly Ash	46
3-11	Chemical Analysis of Incinerator Fly Ash	47
3-12	Incinerator Residues	47
3-13	Incinerator Wastewater Data	48
3-14	Chemical and Physical Data: Three Overburden Grab Samples	50
3-15	Trace Element Content of Coal and Associated Rocks, Core BT249	52
3-16	Comparison of Average Trace Element Concentrations (ppm)	53
3-17	Analyses of Overburden Materials	55

Number		Page
3-18		
(a)	Predicted Operating Conditions and Emissions from Unit 5 and the New Plant Under 100 Percent Load	57
(b)	Peak Ground Level Contaminants from Existing Plant	57
(c)	Predicted Combined Ground Level Pollutant Concentrations from New Plant and Existing Unit 5	58
(d)	Projected Constituents of Ash from the New Plant and Existing Unit 5	58
3-19	Byproduct Water Analysis from Synthane Gasification of Various Coals	60
3-20	Mass Spectrometric Analysis of Benzene-Soluble Tars	61
3-21	Hypothetical Quality of Wastewater, Gillette Treatment Plant	63
3-22	Septic Tank Septage Characteristics as Reported in the Literature	65
3-23	Typical Chemical Composition of Raw and Anaerobically Digested Sludge	67
3-24	Metals in Sludge, 1971-1973	68
3-25	Analysis of Runoff Sample in Third Trench at the City of Gillette Landfill in June 1977	71
3-26	June 1977 Analysis of Water from Stone Pile Creek Behind Gillette Water Treatment Plant	72
3-27	Quantity and Characteristics of Contaminants in Urban Runoff	73
4-1	Major Mine Site Water Usage	76
5-1	Representative Chemical Measurements for Surface Water Quality	90
5-2	Drainage Areas for Lease Sites, Mean Annual Runoff, and 25-Year Peak Discharge	95
5-3	Soil Series Classification of Campbell County	98
5-4	Hydrologic Soil Classifications	105
5-5	Approximate Areal Percentages of Hydrologic Soil Groups	106
5-6	Aquifer Parameters in the Belle Ayr Mine Vicinity	115
5-7	Well Completion Data, WRRI Groundwater Observation Wells, AMAX Belle Ayr South	122

Number Page

5-8 Summary of Aquifer Test Data 127

5-9 Static Water Levels Measured on Uninstrumented Wells 129

5-10 Monitor Well Inventory for AMAX's Eagle Butte Mine 132

5-11 Calculated Values of Transmissivity and Storage Coefficient in Roland Formation 134

5-12 Summary of Elevation of Water Level in Roland Coal, Smith Coal, and Overburden Compared to Elevation of Top of Roland Coal and Smith Coal 138

5-13 Inventory of Wells and Springs, Rawhide Block Near Gillette, Wyoming 140

5-14 Summary of Aquifer Test Data, Kerr-McGee Jacobs Ranch Mine 146

5-15 Description of Monitor Well Completions at Jacobs Ranch Mine 151

5-16 Wyodak Groundwater Monitoring Stations 159

6-1 AMAX Belle Ayr Water Quality Data — Wasatch Formation Above the Coal 166

6-2 AMAX Belle Ayr Water Quality Data—Wyodak Coal 168

6-3 AMAX Belle Ayr Water Quality Data—Scoria Pit—Wasatch Formation Above the Coal 170

6-4 AMAX Belle Ayr Water Quality Data — Fort Union Formation Below Coal 171

6-5 Minimum and Maximum Values for Water Quality Parameters at AMAX Eagle Butte Lease (all aquifers) 173

6-6 Summary of Water Sampling Procedures During Tests of Various Wells at the Eagle Butte Mine 174

6-7 Results of Chemical Analyses of Groundwater from Wasatch Wells 175

6-8 Results of Chemical Analyses of Groundwater from Roland Coal Seam Waters 176

6-9 Summary of Water Quality at Black Thunder Site Surface and Groundwater 179

6-10 Water Quality Analyses of Water Wells on the Rawhide Lease 180

Number		Page
6-11	Minimum and Maximum Values at Carter Oil North Rawhide Lease for Water Quality Parameters (coal aquifers)	181
6-12	Chemical Analysis of Water from Wells within 6 Miles of Property Boundary of Proposed Kerr-McGee Jacobs Ranch Coal Mine	182
6-13	Laboratory Analysis of Water from Stock and Domestic Wells Drilled Prior to Granting of Lease to Kerr-McGee	183
6-14	Groundwater Quality, Hayden Residence, Sun Oil Cordero Lease	185
6-15	Groundwater Quality, Well Number 11, Sun Oil Cordero Lease	186
6-16	Minimum and Maximum Values for Wyodak Mine Water Quality Parameters	187
6-17	Water Quality Analysis Summary	188
6-18	Water Quality Analysis Summary— Gillette, Wyoming, Water Supply, 1976	189
8-1	Characteristics of the Soils	211
10-1	Project Area Potential Pollution Source Priority Ranking by Major Category	228

LIST OF ABBREVIATIONS

ANFO	ammonium nitrate-fuel oil
BOD	biochemical oxygen demand
CEC	cation exchange capacity
COD	chemical oxygen demand
DEQ	Department of Environmental Quality
DMA	designated monitoring agency
DO	dissolved oxygen
DOC	dissolved organic carbon
EC	electrical conductivity
ECe	EC of soil paste extract
ED	electrodialysis
EIS	environmental impact statement
EPA	Environmental Protection Agency
ESP	exchangeable sodium percentage
I/I	infiltration/inflow
JTU (turbidity)	Jackson turbidity units
LLL	Lawrence Livermore Laboratories
MBAS	methylene blue active substances
nd	no date
NPDES	National Pollution Discharge Elimination System
PAH	polycyclic aromatic hydrocarbons
RO	reverse osmosis
SAR	sodium adsorption ratio
SCS	Soil Conservation Service
SV solids	suspended volatile solids
TDS	total dissolved solids
TOC	total organic carbon
TPD	tons per day

Chemicals and Elements

As	arsenic
Be	beryllium
Ca	calcium
Cd	cadmium
CdS	cadmium sulfide
Cr	chromium
Cu	copper
CuS	copper sulfide
Fe	iron
FeS	ferrous sulfide
Hg	mercury
Hg_2S	mercurous sulfide
HgS	mercuric sulfide
Mo	molybdenum
NH_4^+	ammonium
Ni	nickel
NO_2	nitrogen dioxide
NO_x	mixed nitrogen oxides
Pb	lead
PbS	lead sulfide
Se	selenium
SO_2	sulfur dioxide
U	uranium
V	vanadium
Zn	zinc
ZnS	zinc sulfide

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SECTION 1

INTRODUCTION

Groundwater is an important natural resource in the United States. It supplies an estimated 68 billion gallons* per day to the nation's fresh water supply (Murray and Reeves, 1972). Nearly half of the nation's population receives its drinking water from groundwater sources (U.S. Environmental Protection Agency, 1976a).

Emphasis on the need to protect groundwater quality has been provided by the United States Congress through the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500) and the Safe Drinking Water Act of 1974 (Public Law 93-523). These laws give the U.S. Environmental Protection Agency (EPA) a major responsibility for preventing degradation of groundwater resources.

Coal is one of the nation's most abundant energy sources. Because of its low sulfur content, Western coal is generally preferred over Eastern coal for environmental reasons. As a result, Western coal is being strip mined at unprecedented rates.

Traditionally, groundwater monitoring activities have been designed to assess the quantity and quality of groundwater for a particular use. To prevent, reduce, and eliminate groundwater quality degradation, as called for in P.L. 92-500, a monitoring program must do more than this. It must provide a systematic approach for detecting and delineating groundwater pollution before the pollution reaches points of groundwater use, and preferably before the pollutants enter the ground. It must focus on identifying the pollution sources, specific pollutants, and their respective mobilities through the hydrogeologic system. Whether a pollutant reaches a point of water use can no longer be the determining factor as to what constitues groundwater quality degradation.

In response to the high priority placed on Western coal development, the U.S. Environmental Protection Agency awarded a 5-year contract to General Electric—TEMPO of Santa Barbara, California, based on its systematic approach to predictive groundwater quality monitoring. The approach provides for the utilization of a 15-step methodology (Todd et al., 1976) which includes the identification, quantification, and ranking for monitoring of the important sources of groundwater quality degradation within a given study area.

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* See Appendix A for conversion to metric units. English units were used in this report because of their current usage and familiarity in industry and the hydrology-related sciences.

CRITERIA FOR SELECTING THE MONITORING AREA

In 1969, the important coal-producing States in the West – Arizona, Colorado, Montana, New Mexico, North Dakota, Utah, and Wyoming – had 36 strip mines which averaged about 400,000 tons yearly per mine. By 1972, the number of mines had dropped to 28, but production had increased to about 1 million tons per mine. Presently there are approximately 60 existing coal mines in the Western States (excluding Washington, Texas, and Oklahoma), and 1976 production was somewhere on the order of 100 million tons. The Federal Energy Administration estimates that Western coal mines in 1985 will produce approximately 570 million tons from about 150 mines.

The coal strip mining activities within this seven-State area were reviewed by the EPA in order to locate candidate study areas. Once this was accomplished, the candidate areas were rated in terms of the degree of attention they were getting in terms of groundwater quality monitoring activities.

Out of the several candidate areas, the coal field along the eastern edge of the Powder River Basin, located within the State of Wyoming and mostly within Campbell County, was selected for study. Campbell County is reported to contain about 50 percent of Wyoming's coal resources and approximately 84 percent of its known strippable coal. At least 20 billion tons lies within 200 feet of the surface and, therefore, is recoverable by strip mining methods (Breckenridge et al., 1974).

One important long-term objective of this study is to develop a reference manual for use in developing monitoring programs to assess the impact of coal strip mining on groundwater quality in other areas of the Western coal-producing region undergoing similar development. It is anticipated that monitoring activities developed using this manual will eventually become part of a State's overall environmental monitoring program – air, land, and water. As a result, the selection of the areas ideally should be made within a State, by the appropriate State water pollution control agency that, in cooperation with the EPA, carries out the mandates of P.L. 92-500 and P.L. 93-523.

The basis for selecting these areas will be governed, collectively, by a combination of administrative, physiographic, and priority considerations. These factors are reviewed in the following paragraphs and then applied in exemplary fashion specifically to the project area to illustrate the area selection process.

Administrative Considerations

The initiation of a monitoring program requires that a locally designated monitoring agency be specified. In many situations, the requisite agency with the necessary technical staff may be a county, district, State, or regional water organization. Thus, the area to be monitored can often be made to correspond to the jurisdictional area of the designated monitoring agency(DMA).

Selection of the DMA may involve a review of a State's institutional structure. In some instances, it will be readily apparent which agency should be designated as the monitoring agency. In other instances, several agencies may have overlapping responsibility and authority. Situations such as this may require organizational changes to provide an efficiently operated DMA.

Physiographic Considerations

The physiographic basis for selecting monitoring areas results from the fact that groundwater basins are distinct hydrographic units containing one or more aquifers. Such basins usually, but not always, coincide with major surface water drainage basins. By establishing a monitoring area related to a groundwater basin, total hydrologic inflows to and outflows from the basin are fully encompassed.

Priority Considerations

Resource administrators at all levels, Federal, State, and local, are faced with a common problem – how to allocate monetary resources equitably to deal with a host of environmental problems. For political reasons, these individuals must be attentive to the needs of all areas under their jurisdiction. Rarely are funds available in a timely manner to deal with more than just a fraction of the problems brought to their attention. A procedure for establishing priorities for both existing and potential environmental impacts for monitoring and control would be particulalry useful.

The following discussion details the application of the administrative, physiographic, and priority considerations to the selection of Campbell County as the project area, and this is followed by a description of how the priority establishment scheme works, before presenting the results of the first attempt to rank the sources identified in the project area for monitoring.

SELECTION OF THE PROJECT AREA

The eastern part of the Powder River Basin will be subject to the most intensive strip mine development in Wyoming. The major coal fields are located in Figure 1-1. The coal beds along the eastern edge of the basin outcrop along a line trending roughly southeast to northwest. Almost all the strippable coal in these beds is located within Campbell County. In order to select that portion of the coal field best suited to meeting the goals of this research effort, the generalized administrative, physiographic, and priority considerations previously discussed are now applied specifically to the selection of the project area.

Administrative Considerations

A primary administrative consideration is the selection of the DMA. In Wyoming, several candidate organizations for the DMA exist – the State Engineer's Office, the State Geological Survey, and the Department of Environmental Quality (DEQ).

The DEQ, because of its assigned responsibilities for environmental quality, is the State agency most suited to become the DMA. The DEQ has divided the State into five physiographic basins – Big Horn Basin, the Northeast Basin, the Platte River Basin, the Green River Basin, and the Bear and Snake

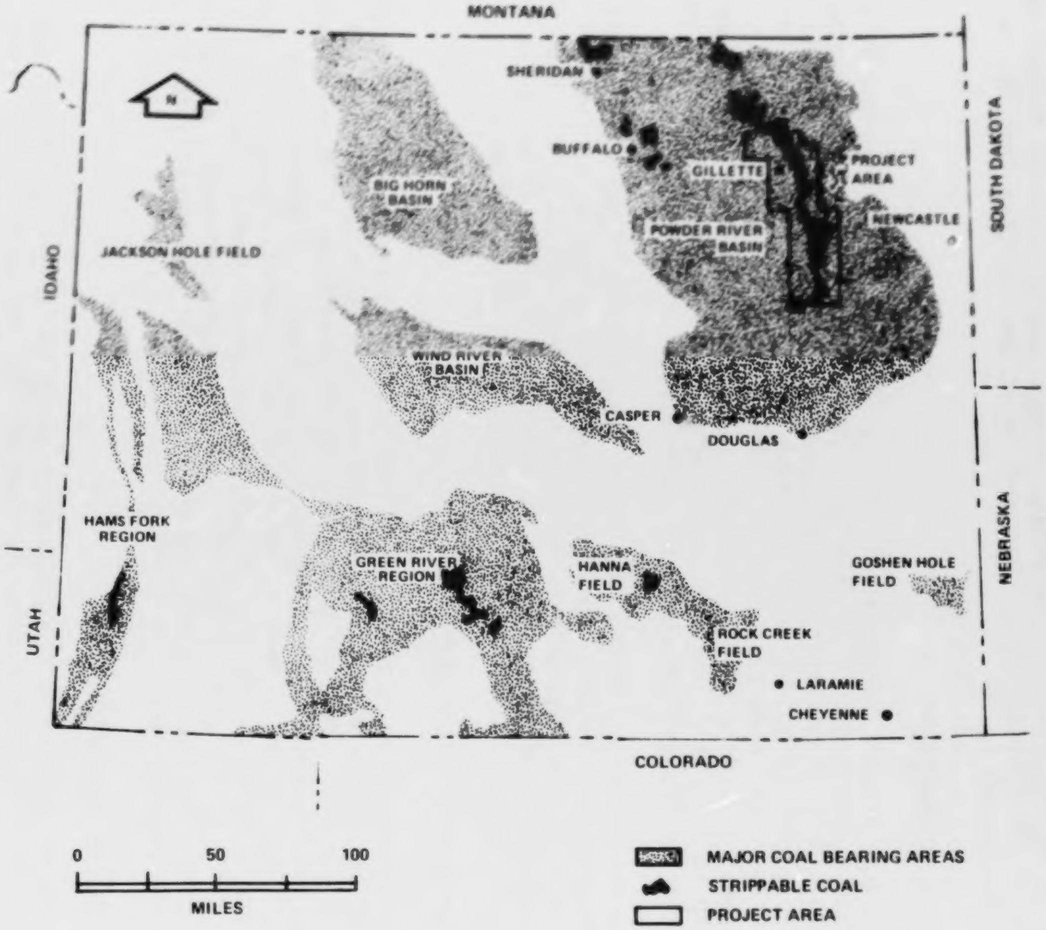

MONTANA
IDAHO
UTAH
SOUTH DAKOTA
NEBRASKA
COLORADO
N
SHERIDAN
BUFFALO
GILLETTE
PROJECT AREA
NEWCASTLE
POWDER RIVER BASIN
BIG HORN BASIN
JACKSON HOLE FIELD
WIND RIVER BASIN
CASPER
DOUGLAS
HAMS FORK REGION
GREEN RIVER REGION
HANNA FIELD
GOSHEN HOLE FIELD
ROCK CREEK FIELD
LARAMIE
CHEYENNE
0
50
100
MILES
MAJOR COAL BEARING AREAS
STRIPPABLE COAL
PROJECT AREA

Figure 1-1. Major coal fields of Wyoming (adapted from U.S. Geological Survey, 1974a).

River Basins. The Northeast Basin encompasses the project area and consists of three subbasins – the Powder River, Belle Fourche, and Cheyenne River.

The Northeast Basin has an engineer in charge of overseeing environmental monitoring activities. He works with the various county and city governments in the execution of the DEQ's responsibilities.

Campbell County lies completely within the Northeast Basin. One important factor in determining the size of the project was to confine the study to a single political unit and to within short distances from an urban center, in this case the City of Gillette. Campbell County provides an area large enough to obtain the necessary regional perspective to provide results which are representative of the impacts on groundwater quality due to coal strip mining in the Powder River Basin and many areas of the Western States.

Physiographic Considerations

Initially, a rectilinear boundary was established to serve as the project boundary until proper physiographic boundaries could be identified. This boundary is shown in Figure 5-1, by the dotted line. The initial boundaries were later superseded by the physiographic boundaries of the five watersheds delineated in Figure 5-1, by heavy black lines. Locally within the above watershed areas, the recharge and shallow groundwater table conforms to the topography and local geology. The coal seams in the area, however, are regional in extent and dip gently in the opposite direction or westerly direction from surface flows.

Priority Considerations

The emphasis of the monitoring program is on water quality changes directly associated with the strip mining of coal. However, various nonmining activities associated with the development of the coal are included in the scope of the program.

The major sources not directly attributed to the mines are municipal (sewage treatment, water treatment, landfills and dumps, and urban runoff), agricultural and livestock production (fertilizers, soil amendments, pesticides, irrigation, stockpiles, and animal wastes), and various industries (e.g., oil and gas extraction and the construction industry).

IMPLEMENTATION OF THE PRIORITY RANKING SCHEME

The priority ranking scheme which follows is designed to progress through the groundwater quality monitoring methodology (Todd et al., 1976) three times, each time at a different level of intensity, each time progressing further into the later steps of the monitoring methodology, and each time accomplishing a different goal.

Level One

The first time through the ranking scheme, several objectives are met: to review the existing data and information on known sources and causes of groundwater pollution, to identify potential sources and causes of groundwater pollution, to identify the potential pollutants associated with both of these pollution source groupings, to evaluate the hydrogeological framework insofar as it relates to these known and potential sources and causes of pollution, and to superimpose these sources and pollutants on the hydrogeologic framework to determine their mobilities. The final goal in this first pass through the scheme will be assignment of monitoring priorities to those sources which appear to present the greatest threat to the area's groundwater quality.

Level Two

Implementation of the monitoring program will require a return to the initial methodology steps. This time the objective will be to verify the preliminary priority ranking of sources with hard data and will involve designing monitoring approaches for each source under investigation. This exercise will require considerable time, depending on the number of sources involved and the size of the area — perhaps several years to a decade or more to reach a mature stage. It is likely that the intensive monitoring will result in a revision of the original priorities. In time, some monitoring activities will need to be decreased or completely eliminated, while others will need to be intensified.

When the results of this second pass through the ranking scheme are used, a much more accurate estimate of the threat to the area's groundwater quality will be available, and controls can be devised to deal with the threat. If the need for instituting controls is obvious after the first assignment of priorities, they should be implemented immediately. The implementation of controls will again require funding by the appropriate State agency.

Level Three

The final pass through the priority ranking scheme will involve monitoring to check on the effectiveness of the controls implemented. If these controls are proven effective, then the intensity of monitoring can be reduced and eventually dropped if the threat can be shown to no longer exist.

New sources of potential pollution will continually appear. The monitoring program should plan to include these sources. They should be brought into the program through the orderly process of Environmental Impact Reviews by State and Federal agencies.

SECTION 2

POTENTIAL SOURCES OF POLLUTION AND METHODS OF DISPOSAL

The basic TEMPO classification scheme for potential sources in the project area includes three major categories: Agricultural, Industrial, and Municipal.

Agricultural activities in the project area are relatively minor. The major agricultural activities are grazing cattle and some dryland farming. Groundwater usage was, and still is, meager for these purposes.

The major emphasis in this study is on coal strip mining, which falls under the Industrial source grouping. A closely related Industrial activity is coal conversion via steam power generation, gasification, or liquefaction.

To meet the needs of the coal mining and allied industries, the City of Gillette, outlying communities, and construction camps will need to provide additional services, e.g., disposal and treatment of liquid and solid wastes, and expanded municipal water supply and treatment facilities. The result of this expansion will be a greater number of potential pollution sources. The impact of these sources has been given detailed review, in particular those related to the City of Gillette.

The potential pollution source inventory which follows summarizes the result of an intensive review of all the published material available in the project area related to proposed development of the seven mines of interest, and numerous discussions with the environmental staffs for those mines. Many discussions were also held with city, county, and State personnel involved in meeting the needs of the coal development and providing adequate environmental controls for this development.

AGRICULTURE

Ninety-four percent of the land in Campbell and Converse Counties is pastureland; consequently, most farming is conducted by livestock operations. The major crops are hay and forage. Very little farmland is irrigated.

According to the Farmer's Cooperative in Gillette, which is the major outlet for agricultural products in Campbell County, very few, if any, soil amendments are used in the county. The County Agricultural Agent stated that very little fertilizer is used. Herbicides are used in the County in small amounts, primarily along highway rights-of-way, and very few pesticides are normally used.

According to the U.S. Bureau of Land Management (1974), grazing of range beef cattle and sheep is the predominant land use in Campbell County. The average ranch is about 260 animal units, one animal unit being year-round support for one cow and calf or five sheep.

The County Agricultural Agent stated (personal communication) that although there is a large amount of livestock in Campbell County, there are no feedlots in the County at this time. The County Agricultural Agent also stated that dead animals are generally left where they fall to be consumed by predators.

INDUSTRY

Two main groupings were used to examine the impacts of potential pollution sources from coal strip mining on groundwater quality, active mining sources, and reclaimed area sources. Active mining sources are those sources which result from the actual mining operations and are of a transitory nature. Reclaimed area sources are those sources which are the result of reclamation activities following the completion of active mining. These sources are expected to remain in place indefinitely.

Active Mining Potential Pollution Sources

Stockpiles—

Stockpiles can act as groundwater pollution sources when rainfall or melted snow percolates through the stored material, dissolving pollutants and transporting them to the groundwater system. They are also subject to leaching due to seepage from ponded surface waters or artificially applied waters.

Classes of material that may be stored in stockpiles during the active mining phase are topsoil, overburden, coal, coal refuse, coaly waste, and the partings that occur between coal seams. Stockpiles may be very temporary or they may exist for the life of a mine.

Topsoil—

In all Powder River Basin coal mines some topsoil will be selectively removed and stockpiled before being replaced on top of graded overburden. Commonly, topsoil from the first area to be mined will be stockpiled because there is no place to use this topsoil at the beginning of mining. For example, in the case of one mine, the topsoil removed from the first area to be mined will be stockpiled until it is used to cover the final area to be mined in about the year 2000. Topsoil might also be stockpiled for blending to upgrade the quality of reclamation soil cover.

Overburden—

As described here, overburden is that material lying between the topsoil and the mineable coal beds. In the area of study, the mineable coal lies at or near the top of the Fort Union Formation and the overburden is sandstone, shale, carbonaceous shale, and thin or impure coal beds of the Wasatch or uppermost Fort Union Formations. In local areas, along the outcrops of coal beds, a unique rock type has been formed by the baking of shale and siltstone by burning coal beds. The baked material is commonly called scoria or clinker and it may also be incorporated in the overburden. An additional type of overburden is the alluvium found in the stream valleys. It consists of sand, silt, and clay derived from the bedrock units. Overburden thicknesses in operating and proposed mines range from none at the outcrop of the mineable coal, up to perhaps 300 feet as the coal beds are traced westward into the Powder River Basin. The thickness of overburden that can be removed at a mine is based on economics and available technology.

During the mining, the overburden is removed, the coal extracted, and the overburden then replaced and graded to the desired topography. Overburden is removed during early development of a mine and is stockpiled because there is no previously mined area in which to place it.

Coal, Coal Refuse, and Coaly Waste—

Coal, coal refuse, and coaly waste are considered together since they are geologically and chemically similar. Coal refuse is used here to mean the fine coal and waste material removed during the coal preparation process. Coaly waste is used here to describe the thin coal seams, impure coal, and carbonaceous shale that may occur in the overburden and within the partings between coal seams. However, these materials are identified separately, in spite of their geological and chemical similarity, because they are handled differently and, therefore, have different water pollution potentials.

Coal, the commercial product, is handled carefully. It is mined soon after exposure by stripping and is not allowed to weather or to have much water percolate through it to pick up pollutants. After mining, it will usually be processed in some manner. Common steps in coal processing include crushing, screening, and washing. Coal at Powder River Basin mines is usually only crushed. After crushing, coal is temporarily stored in silos, bunkers, or open piles. Although open piles are the exception, they may occasionally be used.

Coaly waste is considered separately from the remainder of the overburden because it usually has a different type and amount of water pollution potential. Its geochemical properties also affect its potential as a soil-forming material. Such materials commonly form toxic soils and are thus segregated from the other overburden during mining. A frequent method of handling is to attempt to place the coaly waste at or near the bottom of the spoil. In order to selectively place the coaly waste, it may be necessary to stockpile it temporarily.

Partings—

Partings that occur between coal seams could be considered along with the overburden, rather than as a separate category. The reason for considering partings separately is that they are likely to be different from the "average" overburden because they tend to be principally shale and carbonaceous shale and because their location may be cause for handling them differently from the overburden. Partings might be stockpiled temporarily to allow for selective placement in the spoils.

Explosives—

Either the overburden or coal, or both, may be blasted at a mine, depending on the degree of consolidation of the material. The principal explosive now being used for blasting at the strip mines is an ammonium nitrate-fuel oil mixture known as ANFO. In the case of a complete explosion during blasting, the solid ammonium nitrate would be entirely converted to gaseous forms and ultimately be lost to the atmosphere. In the case of an incomplete explosion, some ammonium nitrate residual will occur. Apparently no studies have been made to determine precisely the amount of residual to be commonly expected in the project area.

Solid Wastes for Road Construction—

A common practice in strip mine development is to construct access and haulage roads from overburden. It has been observed at the mines visited that most permanent roads are being constructed of scoria, or clinker. However, some roads have been constructed of overburden.

Discharges into Pit and Methods of Disposal—

Water entering pits can originate from a number of sources, each of which may already contain pollutants derived in a number of ways. Pit water thus would generally be expected to contain some pollutants. Pit water is eventually disposed by several different methods. As such, the pit discharge is itself a potential source of pollution. The following discussion lists the sources of pit water as well as the methods of disposal of pit discharge.

Water in the pits may come from a number of sources, such as:

- Direct precipitation in the pit
- Runoff into the pit
- Water percolating from nearby stream channels, generally through alluvium along the floodplain
- Liquid wastes (such as septic tank effluent)
- Groundwater in the overburden
- Groundwater in spoils
- Groundwater in the coal seam being mined
- Groundwater in underlying coal seams and strata.

For mines in the Gillette area, the method of disposal for most of the pit discharge will be dust control. Secondarily, the pit discharge will be used for irrigation of reclaimed spoils during the early stages of reclamation. Discharge to surface water will also commonly occur when there is excess pit water compared to potential use.

Supplemental Sources of Water-

Supplemental water for dust control and coal processing may be obtained from pumpage of deep wells or by importing sewage effluent or both.

Pumpage of deep groundwater-It is theoretically possible for poor quality waters pumped from deep aquifers to pollute shallow groundwater systems. However, in the project area, the deeper waters are generally of better quality than shallow waters. Available data indicate that the shallow Wasatch Formation waters have the poorest quality of any waters in the area.

Pumpage from the deep aquifers in the project area is limited to a few subdivisions and the coal mines. All drinking water supply wells for the mines produce from the Fort Union Formation.

Imported sewage effluent-The principal source of sewage effluent for importation in the project area is from the City of Gillette treatment plant. This plant receives not only domestic wastes from the City, but also periodic discharges of industrial wastes.

Sewage flows from the City of Gillette treatment facilities may impact on the quality of groundwater in two ways: (1) seepage losses in Donkey Creek and (2) direct drainage into mine pits. Seepage loss is a function of such factors as temperature and entrained substances. Temperature affects infiltration through viscosity relationships. Entrained substances, particularly sediment, organics, and microorganisms may clog the surface of the channel, reducing intake rates.

The problem of seepage losses in Donkey Creek will be largely eliminated following the completion of a pipeline which will transmit effluent from the City of Gillette to a reverse osmosis (RO) unit at the Wyodak mine. However, seepage losses in the pipeline must also be considered a potential source.

Water treated in the RO unit will be used as process water in the nearby Neil Simpson Power Plant. Brine from the RO unit will be discharged to an evaporation pond for disposal. Leakage from the pond should be considered as a potential source.

Surplus sewage effluent (above requirements for the RO plant) will be used for dust control.

Mine Sanitary Wastes-

Three types of treatment facilities may be used to treat sewage generated in the mine site: septic tanks, package plants, and oxidation ponds.

Septic tanks-Overflow for septic tanks is generally discharged into leaching fields. Areal requirements for leaching fields with continuous inundation should be 0.5 gallon per square feet (gal/ft^2) per day for intermittent operation. Effluent percolating beneath a leach field poses a threat to groundwater quality, particularly if the vadose zone consists of fractured rock. Sludge must be pumped from the septic tank units periodically. Sludge could be used as a soil conditioner, possibly leading to pollution.

Package plants—Prefabricated package plants are generally used to treat sewage for small subdivisions, schools, and other installations, with loadings of 1 million gallons per day (mgd) or less. Package plants operate to provide extended aeration of sewage — a variant of the activated sludge process. Units consist of two compartments: a clarifier chamber and an aerator tank, where air is forced into raw and recycled sewage.

Two problems exist with package plants, vis-à-vis potential impacts on water quality of the receiving stream or groundwater. First, package plants are very sensitive to shock loading, e.g., rapid changes in diurnal flow rates. Treatment becomes relatively ineffective following shock loading such that effluent quality released from the plant becomes very poor. Secondly, because primary settling is generally omitted in commercial plants, discharge of solids may become objectionable.

Oxidation ponds—Oxidation ponds are commonly used in small communities to treat raw sewage. In fact, if designed properly, ponds may attain secondary treatment (U.S. Environmental Protection Agency, 1976b). Three types of ponds are commonly used: aerobic ponds (mechanical aerators), facultative ponds (aerobic-anaerobic) and anaerobic ponds. Basically, aerobic ponds rely on a symbiotic relationship between bacteria and algae to stabilize sewage.

Ponds may leak if inadequately sealed and possibly contribute to groundwater pollution. Generally, a natural seal is induced in time by infiltrating organics.

Mine Solid Wastes—

Solid wastes generated by mining operations (excluding spoil) may be disposed of by one or more of the following:

- Onsite landfills
- Offsite disposal by landfills
- Incorporation in mine spoils
- Incineration followed by land disposal of residue.

Onsite disposal may be accomplished using open dumps or sanitary landfills. Open dumps, as the name implies, consist of dumping solid wastes on the surface of the ground, or over embankments. Occasionally, open dumps are burned. An advantage of onsite landfills, properly designed and constructed, is that the solid waste is concentrated at one place. Monitoring of types of solid wastes is facilitated, as well as groundwater monitoring.

The same discussion given above for onsite disposal applies to offsite solid waste disposal sites.

Solid wastes generated by mining activities are often incorporated with mine spoils and dumped into the mine pit. Groundwater moving into the spoil piles is potentially capable of leaching solid wastes, producing leachate. In contrast to onsite or offsite disposal, solid wastes are generally placed haphazardly in the spoils. Consequently, groundwater monitoring becomes a difficult operation.

Combustible solid wastes may be incinerated to reduce bulk. The residual ash may then be placed in landfills or into spoil piles. Leaching of buried ash may subsequently occur by surface or groundwater influx into the landfill and spoil pile.

Fly ash removed by the incinerator gas stream may settle on the ground surface for considerable distances from the incinerator. Settled ash represents a potential source of surface and groundwater contamination.

Liquid Shop Wastes—

Maintenance and servicing of mine equipment will be likely to produce some liquid wastes, such as oil and wash water. In most cases the mining companies have simply stated that liquid shop wastes will be disposed of in a manner complying with State and Federal regulations, but no details have been given.

Much of the equipment will probably be washed outside, with the water running off onto the ground. Possible pollutants include salts in the material being washed off of the equipment, soap or detergent that may be used, and salts or toxic elements in the water used for washing. Washing will probably be concentrated in a relatively small area near the building and shop.

Spills and Leaks—

Wherever liquids are held, there is the potential for leaks. The mines keep liquids such as gasoline, oil, and diesel fuel in storage tanks, either buried or above ground, and in some cases, pipelines connect these storage tanks with points of use. Package treatment plants, with associated pipelines, and storage vessels for ammonium nitrate and fuel oil also have a potential for leaks.

Spills can occur in the process of transporting all of the above materials and during loading and unloading storage tanks. Lubricants and other materials used for servicing equipment have the potential of being spilled both in the shop and at the pit, depending upon where servicing is taking place.

Reclaimed Area Potential Pollution Sources

Site reclamation fill materials are those that will be within or closely associated with the mined area. After mining, the overburden (spoils) will be replaced within the mined area. The spoils will consist of various subcategories of geologic materials including coaly waste, interseam partings, and refuse from coal preparation, if any is produced. Various solid wastes may also be disposed of within the spoils. This was observed to be the practice at many of the mines, which are reported to be licensed landfills. Topsoil that is determined to be of good quality for plant growth will be spread on the graded spoils. Poor quality soils will be incorporated within the spoils.

These fill material sources may contribute to groundwater pollution in several ways. As with stockpiles, precipitation may percolate through the materials, dissolving soluble chemicals and carrying them to the groundwater system. Additional mechanisms of pollution are percolation of surface water from streams, ponds, and lakes, and the movement of groundwater through the mined area. A common circumstance in Powder River Basin mines is the presence of a stream that passes through the mine area. The streams are being diverted during the course of mining, but subsequently will be rechanneled through mined areas. Ponds and lakes may be developed within the mined area. Some mining plans include a lake in the final strip cut.

Reclamation Aids—

Fertilizers and soil amendments have some potential for groundwater pollution. The AMAX Belle Ayr South mine is reported to be planning application of not more than 20 pounds per acre of nitrogen in the form of ammonium nitrate; in most cases, 20 pounds of phosphorus in the form of superphosphate, essentially monocalcium phosphate. Wood fiber and straw mulches are commonly used in the project area to reduce soil loss and conserve moisture.

The primary fertilizer dealer in Campbell County is the Farm Bureau Co-op. There, nitrogen (ammonium nitrate) is available with a fertilizer grade of 34-0-0, and as a mixture with superphosphate, having an analysis of 18-46-0. One mine buys the 34-0-0 and 18-46-0 fertilizer grades and mixes these to obtain a higher nitrogen content of the applied fertilizer. The Farm Bureau employee was of the opinion that Campbell County is now in the experimental stages of fertilizer application, with some farmers believing strongly in its benefits, and others disclaiming them. Fertilizer is used primarily in Campbell County on wheat, barley, and some grasses.

Ammonium nitrate is manufactured for use in explosives and as a fertilizer. Because it is very soluble in water when used as a fertilizer, it leaves no residue in the soil if sufficient moisture exists to stabilize it. Because the two types of nitrogen salt which compose this fertilizer have the ability to move up and down in the soil solution, it should be considered a potential pollutant.

The cationic nature of ammonium ions permits adsorption and retention by soil colloidal material if the exchange capacity of the soil is sufficiently high; otherwise it will be removed in percolating water.

Once ammonium is nitrified, it is subject to leaching as it is completely mobile in soils. Under conditions of excessive rain and high water table it may reach the groundwater. This downward migration is likely to occur near streams. Where evapotranspiration is greater than precipitation, nitrogen salts may migrate vertically upward to the land surface.

Because the phosphate ion is almost immobile in the soil, phosphorus moves very slowly from the point of placement.

OIL AND GAS EXTRACTION

Oil and gas have been discovered in 210 fields in the Eastern Powder River Basin, Figure 2-1. The remaining recoverable reserves in these fields have been conservatively estimated at 221 million barrels of oil and 508 billion cubic feet of natural gas. Ninety percent of the oil is produced from the early Cretaceous Muddy Sandstone and the Minnelusa Formation of Pennsylvanian age.

According to the Consolidated Oil and Gas Co. (personal communication), in most cases, oil and gas occur together. An oil/gas mixture is pumped out of the well, and the two are separated on the surface. The gas is piped off, while the oil is collected in an onsite battery of storage tanks. When the tanks are full, the oil is tested for water content and is then transported to the customer via pipeline.

A local rancher has reported that leakage from storage tanks is a continuing problem; the oil has polluted the surface water in local drainage. He also reported that during drilling the sides of the mud pits, used for circulating water and drilling mud, broke open several times, releasing mud, water, and oil into a nearby stream. Leaks and spills of this type appear to be an important potential pollution source associated with oil and gas extraction.

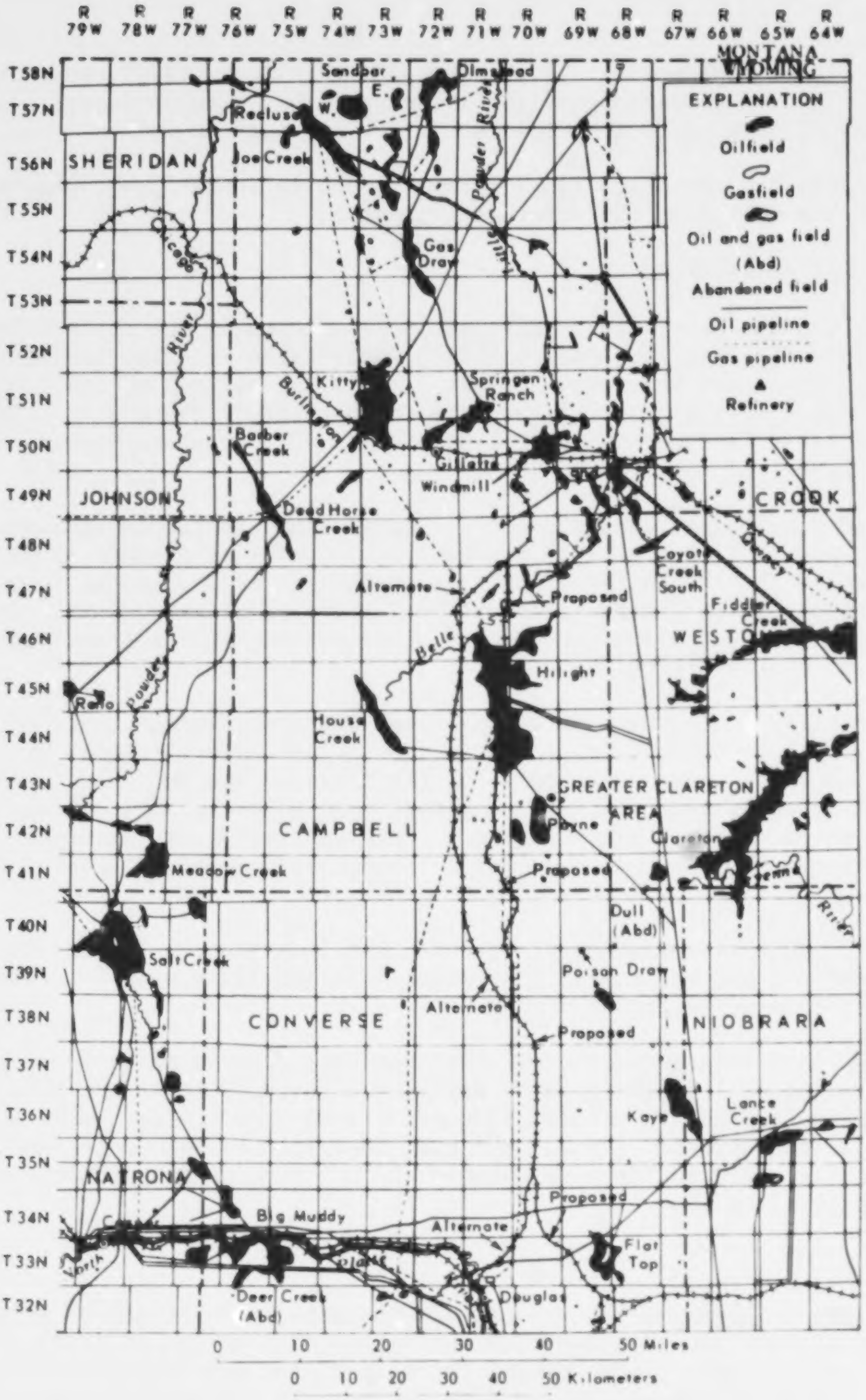
Other potential sources of pollution include seepage through the bottom of the mud pit and the entrance of water into shallow aquifers through leaks in the casings of injection or disposal wells.

Every oil well and test hole that has been drilled had a mud pit associated with the well at the time of drilling. These mud pits are used for mixing drilling mud and for circulating water used in drilling. When a well or test hole is abandoned, the mud pit must be filled in and "reclaimed." No site-specific information is available at this time on evaporation ponds or brine disposal wells.

CONSTRUCTION

Campbell County is the fastest growing area in the State of Wyoming. This growth rate is reflected in large-scale construction activity in the area. Approximately 1,000 housing starts per year are anticipated by the City of Gillette, 600 within the City during 1977 and the balance in adjacent county areas. Also, numerous duplexes and apartment buildings are slated to be built in the coming years.

Industrial construction is also active. A large shopping area is planned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MONTANA
WYOMING
EXPLANATION
Oilfield
Gasfield
Oil and gas field
(Abd)
Abandoned field
Oil pipeline
Gas pipeline
Refinery
Sandbar
E.
W.
Olmstead
Recluse
Joe Creek
SHERIDAN
Powder River
Little
Chicago
River
Gas Draw
Burlington
Kitty
Springen Ranch
Barber Creek
Gillette
Windmill
JOHNSON
Dead Horse Creek
CROOK
Coyote Creek South
Alternate
Proposed
Fiddler Creek
WESTON
Belle
Hilight
Reno
Powder
River
House Creek
GREATER CLARETON AREA
CAMPBELL
Payne
Clareton
Proposed
Meadow Creek
Cheyenne
River
Dull (Abd)
Salt Creek
Poison Draw
CONVERSE
Alternate
Proposed
NIOBRARA
Kaye
Lance Creek
NATRONA
Proposed
Big Muddy
Alternate
North
Flat Top
Deer Creek (Abd)
Douglas
0 10 20 30 40 50 Miles
0 10 20 30 40 50 Kilometers

Figure 2-1. Oil and gas fields associated with the Eastern Powder River Basin, Wyoming (U.S. Department of Interior, 1974)

near the Cut-across Road, south of Interstate 90. East of this planned shopping center, a motel is being built. The facility is scheduled for completion in fall 1978. North of Gillette along Wyoming Highway 14-16, new steel buildings are being erected. The newest building will be a parts depot for mining equipment. Tractor dealerships, welding shops, and other businesses occupy other recently constructed buildings. The Gillette-Campbell County airport is also growing. One company is building new hangars and office facilities, and some individuals are building hangars for their private planes.

Road construction is occurring in the project area. The gravel road from the AMAX Belle Ayr South mine south to the ARCO Black Thunder mine parallels a new railroad line. The road has been widened, new culverts have been installed, and graders keep the surface smooth. The road will eventually be oiled and graveled. Bridges have been replaced on Wyoming Highway 59 near Reno Junction, and road-patching crews operated countywide through the summer of 1977. Wyoming Highway 59, north of Gillette, is being rerouted past the AMAX Eagle Butte mine and the Carter North Rawhide mine.

A north-south railroad line is being constructed from Gillette to the southern end of the project area. The line is complete to approximately 12 miles south of the Sun Oil Cordero mine, and the operating mines have completed spur lines to the main railroad. Field observations indicate that the railroads will be as far south as ARCO's Black Thunder mine by winter 1977.

The most active construction efforts are associated with the surface coal mines in Campbell County. Although many mines will eventually extract Federal and/or private coal, only seven mines within the project area have begun substantial construction.

Methods of Construction Waste Disposal

Construction projects primarily generate solid waste, with limited amounts of waste oil and grease. Housing construction projects dispose of their solid waste at the Gillette Sanitary Landfill. Nonmining industrial construction waste is also deposited at the landfill.

Railroad and highway construction projects use water for dust control. Water service companies haul water to unlined storage pits, from which the construction drivers withdraw water for dust control. Field observations indicate that the water used for these purposes may often be oil field wastewater, or other nonpotable water. The storage pits for this water are usually centrally located for easy access. Leaks and spills from storage tanks are always possible, but few such problems have been observed in the area.

Construction of the surface coal mines generates solid waste and small amounts of waste oil and grease. The mining companies have obtained permits to treat the mining pits as landfills. Therefore, solid wastes and all other wastes generated are dumped into the mining pit and are covered with backfill material. Personnel from the City of Gillette (Jeff Smith, Gillette City Engineer, personal communication, 1977) stated that a large amount of mine construction material is disposed of at the City landfill.

COAL CONVERSION

Steam Electric Power Plants

One air-cooled, coal-fired power plant is currently operating in Campbell County and another, under construction, is scheduled to go on-line in June 1978.

The operating power plant is Neil Simpson Station, owned by Black Hills Power and Light Co., and Pacific Power and Light Co., and operated at the Wyodak mine site. Burning about 400 tons of coal per day, it is capable of producing 30 megawatts of electricity. When the power plant currently under construction begins operation, part of the existing facility will be retired.

Combustion products from burning the coal are heat, gaseous carbon dioxide, water vapor, sulfur dioxide, and impurities such as suspended inorganic noncombustibles. These combustion products and excess air pass through the boiler as flue gases. Next the gases pass through a regenerative air heater where some of the heat is transferred from the flue gases to incoming combustion air. The flue gases then enter an electrostatic precipitator, where suspended fly ash particles are charged by an electrical field. The particles are then attracted to grounded collector plates and are moved down the plates into a hopper by mechanical vibration of the plates. The electrostatic precipitator will remove about 99 percent of the fly ash and may entrain as much as 10 percent sulfur dioxide with the ash. It is designed to treat about 4 million pounds of flue gas per hour. The treated gases will be discharged through a 400-foot stack at an exit velocity of about 90 feet per second during full load operating conditions.

Potential sources of pollution from the power plants include the following:

- Atmospheric emissions
- Fly ash from the electrostatic precipitators
- Neutralized demineralizer regeneration wastes
- Sewage treatment plant effluent
- Floor and equipment drainage and wash water
- Boiler blowdown
- Bottom ash sluicing water
- Pyrites from the pulverizer
- Bottom ash from the boiler
- Ash from the economizer.

The major power plant waste material is fly ash. It is predicted that the new plant will produce approximately 28,000 pounds of fly ash per hour, or nearly 400 tons per day. The ash will be disposed of by using it as fill in both the north and south pits of the Wyodak mine. Once it is deposited in the pit, it will be covered with spoil. Water sprays will be employed at all transfer points in order to minimize dust during ash handling.

Water for boiler makeup will be treated for dissolved solids removal by two parallel demineralizer trains, each consisting of a cation exchange unit and a mixed bed ion exchanger. Periodic chemical regeneration of the demineralizers will be required. Regeneration wastes will be collected in a sump for neutralization to a pH of 6.5 to 8, and will then be disposed of in an ash pond located in the north pit. Bottom ash sluicing water, boiler blowdown, and floor and equipment wash water will also be conveyed to the ash pond. Black Hills Power and Light Co. (1973) states that because the pond will be located on top of a clay bed no seepage of pond water is anticipated.

During construction of the new plant, sanitary wastes from the station and from a nearby residential community are being treated in an extended aeration treatment facility. Following construction, a packaged treatment plant, including primary settling, extended aeration, and gas postchlorination, will be used. It will be designed to treat about 3,500 gallons per day with a 4,000-gallon aeration tank, a 1,000-gallon settling tank, and a 1,200-gallon sludge tank. Treated effluent will be discharged to the ash pond.

Additional solid wastes generated by the power plants are pyrites from the pulverizer, bottom ash from the boiler, and ash from the economizer. Black Hills Power and Light Co. (1973) stated that these will be disposed of onsite.

Gasification

The extensive coal resources of the Powder River Basin, coupled with the need for easily transportable and usable fuels to high-use regions, create the potential for development of coal conversion facilities in Campbell County. Although three types of conversion processes (coal gasification, coal liquefaction, and solvent refined coal) are currently being studied in the United States, no commerical-scale facilities are planned for Campbell County for the immediate future. However, since 1974 Lawrence Livermore Laboratories (LLL) has been conducting experimental in situ coal gasification studies. Their experimental site in the Hoe Creek watershed southwest of Gillette is the only coal conversion activity identified in the study region.

The LLL approach for in situ coal gasification conceptually involves conversion in a thick—50 feet or more—coal seam at depths of 500 to 3,300 feet. Permeability of the reaction zone is created using chemical explosives. A permeable, fractured coal bed surrounded by relatively impermeable strata promotes heat transfer and enhances contact of coal and reactants. LLL anticipates that this will also minimize leakage of reactants and products from the fractured zone. In this sense, the LLL concept has been termed an underground packed-bed reactor.

The fractured zone is ignited at the top. Ignition is initially accompanied by oxygen injection which is replaced by a steam-oxygen mixture after the combustion zone is established. Some of the coal burns to produce process heat, and the steam is a hydrogen source for the gasification reaction. Collection wells are drilled to the bottom of the fractured zone to collect the product gases (methane, carbon monoxide, hydrogen and carbon dioxide). Under commercial operation, these products would be upgraded to pipeline quality in surface facilities.

With the exclusion of surface upgrading facilities the preceding paragraphs provide the salient features of both a commercial-scale in situ gasification facility and the small experimental operation presently existing near Gillette. The remainder of this discussion deals with the specifics of the experimental program as it may result in pollution sources.

The actual gasification phase of Hoe Creek Experiment No. 1 occurred in October 1976. Activities leading to the actual burn included:

- Hydrologic and geologic exploration
- Fracturing of the coal seam
- Placement of inlet, outlet, dewatering and environmental monitoring wells
- Dewatering of fractured zone
- Gasification experiment.

These activities are to varying degrees potential causes of pollution.

Prior to development of the gasification experiments, exploratory holes were drilled at the Hoe Creek area to characterize the site geology and hydrology (Stone and Snoeberger, 1976). Pump and observation wells were installed for pump tests. These were subsequently used for dewatering and environmental monitoring. Potential sources of pollution from these activities include discharge from pump tests and interconnection of aquifers from faulty well construction.

Fracturing of the Coal Seam—

Prior to gasification, the coal seam was fractured to enhance permeability and product recovery efficiency. A slurry of explosive material called Pourvex EL-836 was used (Stephens and Madsen, 1977). The composition of this explosive is not available. However, explosive residues are a potential pollutant. Additionally, the fracturing of the coal seam altered the hydrologic characteristics of the formation and may lead to enhanced movement of gasification byproducts from the area.

Placement of Experimental Wells—

To provide access to the fractured zone and adjacent strata, a variety of injection (gas), outlet (product), dewatering, and environmental monitoring wells were constructed (Figure 2-2). These wells are potential pollution sources by acting as conduits between different aquifers, from the burn zone to other aquifers, and from the burn zone (or aquifers) to the surface.

Dewatering—

After the coal seam was fractured, this zone was dewatered by pumping the six dewatering wells and well P-1. Pumping was continued with only short interruption throughout the entire experiment. Water production rates are shown in Figure 2-3 and water level response in the various site wells is presented in Figure 2-4. The method of disposal of this water is unspecified. At equilibrium, the dewatering produced less than 10 gallons per minute (gpm).

Gasification Experiment—

The fractured coal bed for Hoe Creek Experiment No. 1 was ignited on October 15, 1976. After one day of operation, an override occurred and essentially only the top layer of the fractured zone was gasified. An override had been predicted from the results of post-fracturing analyses. Gasification ended October 26, 1976. Approximately 130 tons of coal (16 percent of the fractured zone) had been consumed. Although the burned zone for this experiment was small, a source of release of the byproducts of pyrolysis, carbonization and coking of coals, and partial combustion byproducts was created. Subsequent water movement into and through the burned zone may affect the water quality of area aquifers. Releases at the surface by dewatering wells during subsequent pumping are, for environmental monitoring purposes, also a potential source of pollution.

Subsidence of the burned area after fracturing and gasification is a possibility. Subsidence may alter the alignment of shallower strata creating conditions of either aquifer interconnection or blockage. Surface subsidence may also disrupt runoff patterns and affect recharge.

Hoe Creek Experiment No. 2—

The gasification phase of Hoe Creek Experiment No. 2 is expected to take place in October 1977. The Hoe Creek 2 site is located about 330 feet from the site of Hoe Creek Experiment No. 1. The coal seam is approximately 25 feet thick with the top located 118 feet below the surface.

Whereas Hoe Creek Experiment No. 1 was a small-scale two-hole gasification project, Hoe Creek Experiment No. 2 will be carried out with a five-spot array (Figure 2-5). One injection well will be centrally located with four collection wells arranged around it in a square pattern. Approximately 1,500 pounds of chemical explosives will be used for fracturing in the central injection well and in each of four other explosives holes, arranged in a square pattern rotated 45 degrees from the square defined by the collection wells. The explosives holes are arranged to maximize resource recovery by placing the areas of highest permeability in the longest flow paths. Small explosive charges may also be placed in the outer flow-holes to reduce flow resistance in the regions where flow lines converge. The dewatering holes will also be placed to maintain symmetry and maximize resource recovery.

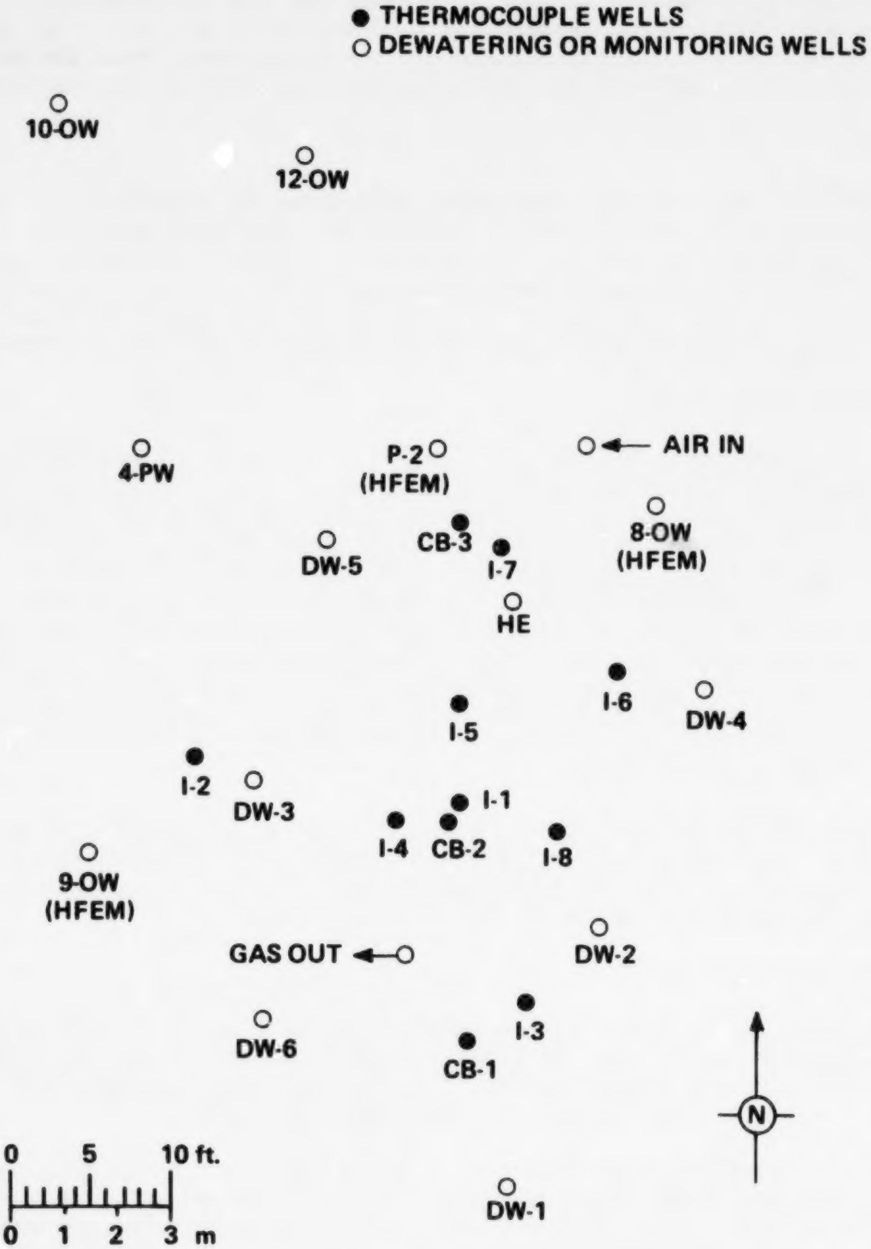

● THERMOCOUPLE WELLS
○ DEWATERING OR MONITORING WELLS
10-OW
12-OW
4-PW
P-2
(HFEM)
AIR IN
8-OW
(HFEM)
CB-3
I-7
DW-5
HE
I-6
DW-4
I-5
I-2
DW-3
I-1
I-4
CB-2
I-8
9-OW
(HFEM)
GAS OUT
DW-2
I-3
DW-6
CB-1
N
0
5
10 ft.
0
1
2
3
m
DW-1

Figure 2-2. Hole bottom locations (Hoe Creek Experiment No. 1) (Lawrence Livermore Laboratory, 1977).

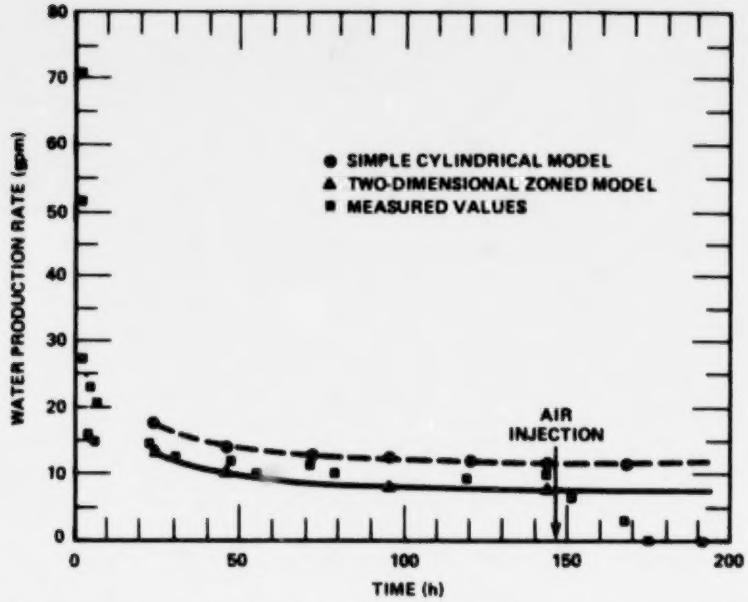


Figure 2-3. Comparison of measured and calculated water production rates for the Hoe Creek Experiment No. 1 site (Lawrence Livermore Laboratory, 1977).

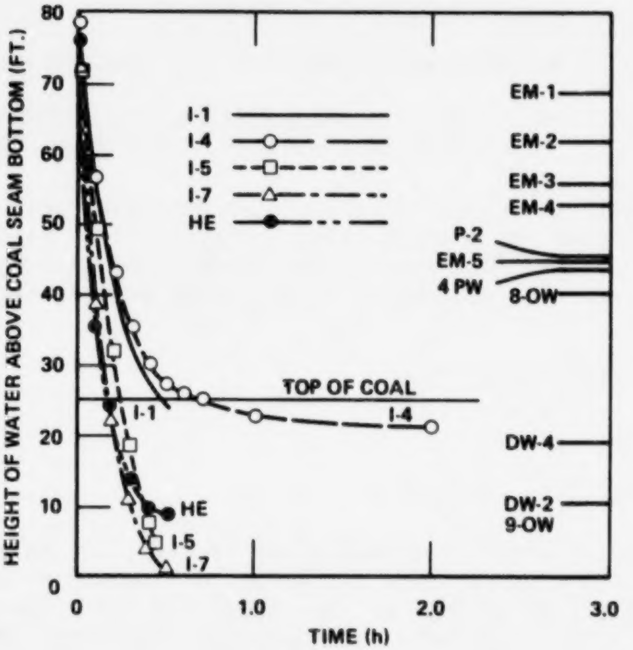


Figure 2-4. Water levels at several locations within the fracture zone as a function of time after the start of dewatering; levels indicated on the right are those reached after 3 to 5 days of pumping (Lawrence Livermore Laboratory, 1977).

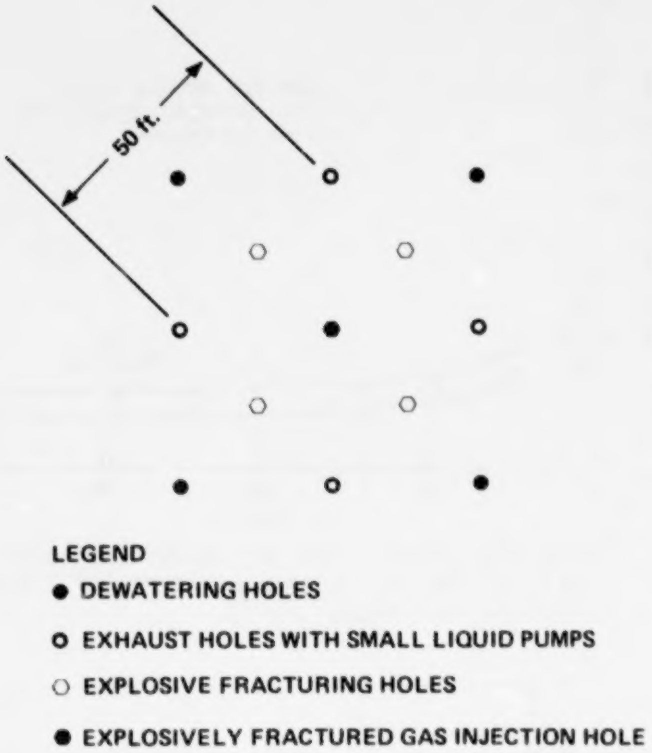

50 ft.
LEGEND
● DEWATERING HOLES
○ EXHAUST HOLES WITH SMALL LIQUID PUMPS
○ EXPLOSIVE FRACTURING HOLES
● EXPLOSIVELY FRACTURED GAS INJECTION HOLE

Figure 2-5. Plan view of the packed-bed experiment (Lawrence Livermore Laboratory, 1977).

The coal will be ignited in the center explosive well at the top of the seam and burned down and outward using an oxygen/steam blast. Condensed liquids (primarily water) that precede the flame front will be removed through the exhaust holes. The dewatering holes may be used as back-up exhaust holes if needed.

MUNICIPAL SOURCES OF POLLUTION

Sanitary Wastes

Sewage Treatment Plant Effluent—

The City of Gillette treatment plant receives not only domestic wastes from the City, but also periodic discharges of industrial wastes and snow melt. Its capacity as of May 1977 was about 1.7 mgd. The treatment plant was originally intended to be a secondary-type facility. Primary treatment is minimal, however, with only a screen provided to remove the solids. A follow-up grit chamber and sedimentation tank were not included. Thus, the secondary unit comprising activated sludge aeration tanks functions in part also for primary treatment. The capacity of these tanks has been reduced by accumulation of sand and other material. Because of ineffective treatment in the aeration tanks, the clarifier or final settling tanks are also overloaded. Effluent discharging from the plant is piped to a "polishing" lagoon which may or may not function as an oxidation pond.

Because of the high water table at the plant, leakage from the aeration and clarifier tanks may be occurring, introducing essentially raw sewage into groundwater. Leakage from distribution lines onsite and seepage from the oxidation pond should also be regarded as potential sources.

Effluent discharging from the pond drains into Donkey Creek. Aerial photography of the area (U.S. Environmental Protection Agency, 1976d) indicates that effluent may flow for a considerable distance downstream in the creek.

Sewage flows from the Gillette treatment facilities may impact on the quality of groundwater in two ways: (1) seepage losses in Donkey Creek, and (2) direct drainage into mine pits. Seepage loss is a function of such factors as temperature and entrained substances. Temperature affects infiltration through viscosity relationships. Entrained substances, particularly sediment, organics, and microorganisms may clog the surface of the channel, reducing intake rates.

Sewage Sludge—

Sewage sludge consists of a mixture of sewage and settled or suspended solid matter issuing from the final sewage treatment process. The quantity and character of sludge depends to a large extent on the treatment process. For example, sludge from the secondary settling tanks of an activated sludge process may contain 13,500 gallons of sludge per million gallons of sewage (Health Education Service, nd), and a moisture content of 98 percent. The nominal weight of dry solids from the process is 2,250 pounds per million gallons (Health Education Service, nd). The process of sludge digestion is intended to reduce the volume of liquid, thereby reducing the total volume; and also to stabilize the organic matter.

A number of methods are available for disposing of sludge, including landfilling, incineration, and application to cropland.

The technique for handling sludge at the Gillette treatment plant involves settling in a pond and/or flooding onto a nearby field. No plans are currently underway to use the sludge for agriculture because of fears that zinc or other heavy metals may cause crop damage.

Sludge disposed of by the Gillette treatment plant may impact groundwater through seepage from the settling pond and during spreading in the nearby field.

Sewerline Leakage—

Leak-free sewage systems are nonexistent. It is difficult to prevent small leaks in new systems, and older systems develop cracks and leaks with age. Most sewerline leaks are quite minor, and can often go totally undetected. Major sewerline leaks can be detected by puddling of sewage and/or odor problems.

According to City officials, sewerline leakage is not a major problem in Gillette. No problems of this type have been reported during 1977. However, potential leakage problems are developing. Sewerlines in the older parts of town are approximately 40 to 50 years old and they are probably in poor repair.

In summary, sewerline leaks are potential sources of pollution. During spring runoff periods, much puddling of surface runoff occurs, and infiltrating waters could conceivably carry sewerline leakage to the groundwater body. However, shallow groundwater in the Wasatch Formation is discontinuous, and the infiltrating pollutant might never reach groundwater. Moisture curves in the vadose zone would have to be determined before a complete analysis would be performed; the apparent minor nature of this problem, however, discounts the use of the procedures.

Septic Tanks—

Although septic tanks are in both Campbell County and the City of Gillette (as well as package plants), an inventory of numbers and locations is not currently available.

Water Treatment Plant

The water supply for the City of Gillette is drawn from more than 25 wells located north of the City. These wells are generally described as "hard" or "soft" water wells. The number of hard water wells exceeds soft water wells. Total hardness ranges from a trace (in soft water wells) to 2,425 parts per million (ppm), as $CaCO_3$ (Nelson et al., 1976). Recently (June 1977), average hardness of raw water entering the Gillette Water Treatment Plant was 128 ppm, $CaCO_3$.

The Gillette Water Treatment Plant was described by TOUPS, Inc. (1977) as follows:

> The Gillette water treatment facilities are located along the north edge of the City...They consist of a degasifier, a raw water storage tank, a lime softening plant, and an electrodialysis plant, all constructed in 1972. The general condition of the treatment facilities is poor, showing a need for substantial repair and maintenance work.
>
> Water from the soft water wells is pumped directly into the treated water storage tanks with no treatment other than chlorination, thus bypassing the water treatment facilities.
>
> Water from the Fox Hills and hard water wells is pumped to the first step in the treatment process, which is a Permutit tray degasifier, designed to remove carbon dioxide, hydrogen sulfide, and the oxidation of iron. Water flows by gravity from the degasifier to the raw water storage tank, which is a 42-foot diameter steel reservoir with a capacity of 250,000 gallons. A valve

vault at the base of the tank can be used to control the flow of water to the next step, which is pretreatment by partial lime-softening and iron removal.

A chlorine feed system for the water supply is located near the main pump station. Metering equipment consists of three Fischer and Porter chlorinators. The chlorine feed equipment and accessory equipment do not meet minimum standards set by the State of Wyoming.

As of June 1977 the electrodialysis plant was not operating because of severe coating of the electrodialysis (ED) plates with precipitated salt. Apparently, raw water was introduced to the system without prior softening.

Sludge from the water softening process, consisting of calcium and magnesium salts, is presently taken to the City of Gillette landfill for disposal. Slurry discharged from the softening process is discharged into Stone Pile Creek (Burlington Ditch) immediately to the north of the plant creating a direct source of potential groundwater pollution.

Landfill or Dumps

The Gillette landfill is located southwest of the City on a hill. In the southwest corner of the site are stockpiled the so-called "white goods," mainly metals such as automobiles, 55-gallon oil drums, discarded tires, wooden furniture, etc. North of the metal disposal area is a pit in which oily wastes have been dumped, along with some metals. Pesticide containers and wastes are accepted. Runoff enters this pit from a local area. Near the pit is an area where open burning is permitted. Down the hill, on the north end, are three long parallel trenches. Each is about 30 to 40 feet wide, 400 to 500 feet long and a maximum of 20 to 30 feet deep. The coal almost extends up to the land surface and was removed and piled on the sides of each trench. Surface runoff readily flows into the trenches and possibly into the buried solid wastes.

West of the two lower trenches is another pit, about 100 feet long and 200 feet wide—the so-called dead animal pit. South and east of the three trenches and up nearer the 2-million gallon City water tank are two additional pits. These pits contain oily wastes and septic tank pumpage. Garbage also is scattered about.

South and slightly up the hill from the oily waste ponds is an area marked for "tires only." Oily wastes have also been discharged into this area.

The presence of surface water running into the landfill trenches is ideal for the production of leachate. In fact, leachate plumes in the shallow aquifers should be considered a definite possibility.

Urban Runoff

Urban runoff and related pollution sources in the Gillette area include the runoff itself, traffic-associated pollutants, and street and highway deicing salts. Specific sources in urban runoff include settled dust, fly ash, solids from off-street mud, automotive exhaust, organic debris from tree leaves, grass trimming, and discarded litter (McElroy et al., 1976). Another primary source in the urban environment is fecal matter from domesticated and indigenous animals. Motor traffic contributes particulate materials and nutrients which accumulate in the surfaces of roadways. Deicing salt is applied to roadways during winter and spring months.

Miscellaneous Potential Pollution Sources

Miscellaneous potential sources of groundwater contamination in the City of Gillette include: (1) sources relating to recreational activities, e.g., leakage from Gillette Fishing Lake; and (2) discharge of sources to washes, e.g., road oil leaking from containers near the City of Gillette Treatment Plant into Stone Pile Wash.

Other Municipalities

The major population centers outside the Gillette city limits are: Rawhide Village, Collins Heights, Wyodak Construction Camp, Hidden Valley, Westridge, Heritage Village, and Wright, Wyoming. Table 2-1 details the methods of waste disposal at each of these areas.

TABLE 2-1. OTHER MUNICIPALITIES

		Sewage treatment			
Development	Water supply	Sewage effluent	Sewage sludge	Septic tanks	Dumps
Rawhide Village and Trailer Park	Fort Union wells	Small, ephemeral channel	Trucked to City treatment plant	None	None
Collins Heights	Fort Union wells	None	None	1 tank/ 1 acre lot	None
Wyodak Construction camp	Fort Union wells	Donkey Creek	Trucked to City plant	None	None
Hidden Valley	Fort Union wells	Small, ephemeral channel	Trucked to City treatment plant	None	None
Westridge	Fort Union wells	None	None	1 tank/ 1 acre lot	None
Wright	Fort Union wells	Small, ephemeral channel	Uncertain	None	None
Heritage Village	Fort Union wells	Small, ephemeral channel	Trucked to City treatment plant	Some in early subdivision (Anderson)	None

Virtually all the water supply is from wells drilled into the deep Fort Union aquifers. The waters are low total dissolved solids (TDS), sodium bicarbonate types that are superior to the City of Gillette's municipal supply.

Sewage disposal is achieved by package sewage treatment plants or septic tanks. Treatment plants are located at Rawhide, Wyodak, Hidden Valley, Heritage Village, and Wright. Liquid effluents are discharged into small holding ponds which empty into local ephemeral channels. Sewage sludge is, as a rule, trucked to the City of Gillette sewage treatment plant and is disposed with the City's sewage sludge. Septic tank areas include Westridge, Collins Heights, and the Anderson subdivision (adjacent to Heritage Village).

No dumps or landfills are located at the subdivisions. Garbage and trash are collected and hauled to the Gillette-Campbell County landfill. Plans for such facilities at Wright, Wyoming, are currently being contemplated.

Local runoff is uncontrolled and, in all cases, runs downhill to the nearest stream channel. Due to the small size of most of these subdivisions, and also due to their suburban character, the pollution potential of local runoff is minimal.

In summary, monitoring programs dealing with the subdivisions should concentrate on the effluents discharged by the package sewage treatment plants. Sewage sludge and solid waste are disposed of at City facilities, strengthening the need for monitoring at these locations.

SECTION 3

POTENTIAL POLLUTANTS

AGRICULTURE

Major potential pollutants from the use of fertilizers in Campbell County are nitrogen, phosphorus, and possibly potassium. The major pollutants associated with livestock in Campbell County are nitrates and organic components of animal waste. The major weed killer used is 2,4-D. Potential groundwater pollutants resulting from irrigation and leaching include primarily the soluble salts calcium, magnesium, sodium chloride, sulfate, and bicarbonate; however, irrigation is limited in the project area.

COAL STRIP MINING

Active Mining Sources

Active mining sources identified in this report include stockpiles consisting of topsoil, overburden, coal ore, coal refuse, coaly waste, and partings. These materials are discussed in the following paragraphs.

Topsoil—

Certain trace elements may be present in topsoils in the Powder River Basin that can be significant groundwater pollutants. Summary analyses of trace elements in near-surface materials in the Powder River Basin are given by the U.S. Geological Survey (Keefer and Hadley, 1976).

Soluble salts that have been concentrated in some soil series are potential water pollutants. These salts have been concentrated by ponding and evaporation of runoff, by evapotranspiration of soil moisture, and by lack of leaching in soils of low permeability. Soil salinity values are given in the Eastern Powder River Coal Basin environmental impact statement (EIS) and in some mine EISs.

Topsoil characteristics for four mines are summarized in Table 3-1. Ranges for the sodium adsorption ratio (SAR), electrical conductivity, and pH along with the number of samples analyzed are given. No data are available for ARCO Black Thunder, Carter North Rawhide, and Kerr-McGee Jacobs Ranch mines.

Major soil series on the Eagle Butte lease were analyzed for boron, cadmium, lead, and mercury concentrations (see Table 3-2). In another analysis boron was found to range from zero to 1.01 ppm with an average of 0.47 ppm on Sun Oil's Cordero mine. Selenium found at the Wyodak mine ranges from less than 0.01 to 0.06 ppm averaging 0.01 ppm with boron concentrations between 0.2 and 2.0 ppm averaging 0.81 ppm. Trace element analyses are not available for the other mines.

TABLE 3-1. SITE-SPECIFIC TOPSOIL CHARACTERISTICS

Mine	Sodium adsorption ratio			Conductivity[a]			pH			Number of samples
	min.	max.	ave.	min.	max.	ave.	min.	max.	ave.	
AMAX Belle Ayr South	0.2	7.5	2.62	0.13	1.53	0.81	7.2	8.1	7.6	86
AMAX Eagle Butte	0.3	5.1	2.19	0.13	-	1.04	7.6	8.2	7.95	20
Sun Oil Cordero	0.18	16.18	5.62	0.13	21.3	5.68	6.2	8.2	7.6	58
Wyodak	0.5	8.9	5.0	0.0	2.18	0.052	7.3	9.2	8.4	43

[a] Conductivity measured in mmhos/cm.

TABLE 3-2. CONCENTRATIONS (ppm) OF TRACE ELEMENTS BORON, CADMIUM, LEAD, AND MERCURY IN SOILS ON THE EAGLE BUTTE MINE PROPERTY

	B	Cd	Pb	Hg
Terry series	0.18	0.52	1.95	0.27
Vona series	0.12	0.52	1.99	0.31
Maysdorf series	0.08	0.50	2.36	0.39
Renohill series	0.29	0.66	2.65	0.36
Bidman series	0.25	0.53	2.00	0.18
Goshen series	0.48	0.57	1.81	0.32
Arvada series	1.94	0.56	3.28	0.40
Shingle series	0.13	0.54	2.44	0.58

Overburden—

As is the case with topsoil, a potential water pollutant in overburden is soluble salts. For example, the soluble salt content of six overburden samples from the Sun Oil Company Cordero mine ranged from 0.04 to 0.88 percent by weight (Dames and Moore, 1974). Using these values, and an assumed dry weight of 1.5 tons per cubic yard for overburden, there would be from 1.2 to 26.4 pounds of soluble salt per cubic yard. Each acre-foot of overburden contains 1,613 cubic yards. Therefore, each acre-foot of overburden might contain from 1,936 to 42,583 pounds of soluble salts.

The possibility of trace elements in the overburden becoming important groundwater pollutants has been and still is of concern. Because of this, trace element analyses have been performed on overburden from most, if not all, of the Powder River Basin mines that now exist or are under active development. The significance of the analyses remains to be interpreted.

Analysis of conductivity, sodium adsorption ratio, cation exchange capacity, pH, and trace elements from cores of the overburden taken throughout the study area are summarized in Table 3-3. Trace element analyses also are available for ARCO Black Thunder and Wyodak mines.

Electrical conductivity (EC) maximum values range from 4.2 to 8.0 micromhos per centimeter (mmhos/cm) throughout the study area. Values less than 8.0 mmhos/cm are indicative of only moderately saline conditions (Wiram, nd). High EC values are found for samples taken within 5 feet of the surface on the Belle Ayr South mine. For deeper overburden, salt concentrations are usually less than 2.0 mmhos/cm which is considered to be insignificant (Wiram, nd) and would have negligible effect on plant growth.

The major anions responsible for the observed EC values on the Eagle Butte lease are, in order of abundance: sulfate, chloride, bicarbonate, and nitrate. The major source of sulfate is gypsum and epsomite ($MgSO_4$-FH_2O). Sodium chloride and other evaporites are sources of chloride and calcium carbonate and complex carbonate sulfates are sources of bicarbonate. Soluble nitrates may be formed by the nitrification of exchangeable ammonium nitrogen (Power et al., 1974).

High SAR values were also found in the uppermost 5 feet. The maximum value was 17.6. According to Wiram (nd), SAR values greater than 12.0 indicate potential problems in permeability and structural stability. They are indicative of an imbalance between sodium and calcium plus magnesium ions within the montmorillonite clay, which reduces permeability to practically zero. For deeper overburden, SAR values average 3.5, indicating that the clay minerals are saturated with calcium and magnesium. Shales and mudstones, in general, were found to have slightly higher SAR values than associated sandstones.

High cation exchange capacity (CEC) values were found for all shales and mudstones. The average is 16.8 milliequivalents per 100 grams (meq/100 g) with a maximum value greater than 30 meq/100 g. These values reflect a high content of montmorillonite clay. CEC values for unconsolidated sands and sandstones are considerably lower, averaging 8.5 meq/100 g.

Wiram (nd) suggested that continued surveillance will be required if any irrigation is done during revegetation of stockpiled or backfilled overburden. Without the use of proper soil amendments, toxic saline and soil permeability problems can be anticipated.

Almost all of the overburden samples were found to have a pH greater than 7, with the values ranging from 3.6 to 8.7. Wiram (nd) states that a pH greater than 8.2 could result in an undesirable soluble carbonate content and low solubility of calcium salts.

TABLE 3-3. SITE-SPECIFIC OVERBURDEN CHARACTERISTICS

Mine	No. of samples	Conductivity[a]			SAR			CEC[b]			pH			Elements[c]								
		Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	Cd	Hg	Pb	Zn	Ni	Cu	S	As	Se
AMAX Belle Ayr South	74	-	6.2	-	-	17.6	3.5	-	30.0	16.8	5.3	8.2		0.23	0.08	1.0	-	-	-	-	-	-
AMAX Eagle Butte	92	-	6.5	-	-	-	3.3	12.8	36.0	27.5	5.0	8.5		0.17	0.05	0.43	-	-	-	-	-	-
ARCO Black Thunder	41[d]	-	-	-	-	-	-	-	-	-	-	-		3.44	0.12	35	-	-	33.8	-	0.8	-
Carter North Rawhide	11	0.7	4.2	1.9	-	-	-	13.0	33.0	-	7.4	8.7		-	-	-	-	-	1.7	168	-	-
Kerr-McGee Jacobs Ranch	55	0.5	5.5	-	-	-	-	11.0	32.0	22.7	7.8	8.4		-	-	-	-	-	0.88	167	-	-
Sun Oil Cordero	89	0.5	8.0	-	0.3	7.2	-	3.9	48.4	-	3.6	-		0.1	0.07	4.3	14.8	2.1	-	-	-	-
Wyodak	7[d]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.47	487	-	0.1

[a] Conductivity in mmhos/cm

[b] Cation exchange capacity meq/100 g

[c] Average concentrations in ppm

[d] Trace element analysis only

Five overburden samples from Belle Ayr South were found to have a total sulfur content greater than 1.0 percent, with the others rarely exceeding 0.3 percent. Of the five samples, two contained fine-grained pyrite and others had large amounts of gypsum and carbonaceous matter. Gypsum crystals and soluble sulfate salts are the major sources of sulfur in the overburden. Sulfate concentrations were found to range from 20 to 40 meq/liter. It is present primarily in the form of the mineral selenite ($CaSO_4 \cdot 2H_2O$).

A potential problem of trace element concentrations of cadmium and mercury may arise. Several examples are shown in Table 3-3 and exceed natural background levels. Other trace element concentrations are summarized in Table 3-3. Arsenic was found on the Black Thunder lease ranging from less than 0.05 to 7.75 ppm, averaging 0.80 ppm. Selenium was found in concentrations less than 0.1 ppm for all samples taken on the Wyodak mine.

Coal, Coal Refuse, and Coaly Waste—

Coal, coal refuse, and coaly waste probably contain some soluble salts, although no analysis of the soluble salt content of these materials has been found in the literature or in unpublished reports. The soluble salts are expected to be principally in the form of crystals of gypsum or similar minerals formed in open fractures. Intergranular pores are not present in the coal and coaly strata as they are in the rest of the overburden.

Sulfur is universally found in coal and carbonaceous strata, but in different forms and in varying amounts of those forms. The two general forms of sulfur that occur in and with coal are inorganic sulfur and organic sulfur. Inorganic sulfur occurs primarily as pyrite or marcasite, which are both iron disulfide (FeS_2).

Acid drainage from coal strip mines is an important problem in eastern coal mining states, but has not been recognized as a serious problem in most western coal mining areas. One of the characteristics of Powder River Basin coals is the low sulfur content. This is probably the reason that acid drainage has not been a problem in the area. However, some pyrite oxidation does occur as is evidenced by the spontaneous combustion of coal piles along the base of the high wall of the Wyodak mine. Apparently the acid that does form from oxidation of pyrite in Powder River Basin coal and associated carbonaceous strata is rapidly neutralized, probably by carbonate minerals in the soil and overburden, and does not cause measurable lowering of the pH of surface water and groundwater. It will, however, contribute dissolved solids in the form of sulfates, probably principally calcium and magnesium. The acid that is formed might also dissolve some trace metals before it is neutralized. As far as is known, no studies have been made of the amount of acid formed in Powder River Basin strata as a result of coal strip mining and of the fate of the acid that is formed.

A number of measurements have been made of the trace elements in Powder River Basin coals. Keefer and Hadley (1976) presented a summary of analyses of 15 coal samples from the Wyodak mine and 11 samples from the Belle Ayr mine. A few trace elements are present in coals in amounts greater than in the overburden and the earth's crust as a whole, but these trace elements have not yet been identified as actual water pollutants so far as is known. Trace element and sulfur content of coal samples are summarized in Table 3-4.

TABLE 3-4. SULFUR AND TRACE ELEMENT CONCENTRATIONS IN COAL SAMPLES

	Sulfur	Average trace element (ppm)						
	(%)	Cd	Hg	Pb	As	Se	U	Cu
AMAX Belle Ayr South[a]	0.25-0.6[e]	0.1	0.13	2.7	2.5	1.1	1.0	-
AMAX Eagle Butte[b]	0.14-1.0[e]	-	0.1	1.0	1.1	0.31	1.1	-
ARCO Black Thunder[c]	0.09-0.59[e]	0.36	0.19	11.62	0.15	-	1.5	-
Carter North Rawhide[c]	0.28-0.52[e]	-	0.1	1.0	1.1	0.13	1.09	-
Kerr-McGee Jacobs Ranch[c]	1.06	<0.001	<0.001	-	0.02	-	-	0.002
Sun Oil Cordero[d]	0.30	0.66	0.1	2.1	2.1	0.44	-	-
Wyodak[c]	0.59	0.1-0.16[f]	0.09	9.12	1.0-2.0[f]	0.86	0.88	-

[a] U.S. Geological Survey (1975).

[b] U.S. Geological Survey (1976).

[c] U.S. Bureau of Land Management (1974).

[d] U.S. Geological Survey (1976a).

[e] Range of sulfur concentrations.

[f] Range of trace element concentrations.

Partings—

Analyses of the chemical nature of partings have been more limited than those for other overburden but those that have been done tend to confirm that the same elements are present.

The U.S. Bureau of Land Management (1974) states that chemical analyses were run on two samples of the parting material between the coal seams, at the Carter North Rawhide mine. Electrical conductivity values were found to be 2.4 and 0.8 mmhos/cm. Values for cation exchange capacity were found to be 73.0 and 11.0 meq/100 g, indicating the high clay content of the parting. Both parting samples were found to be acidic, with pH values of 4.9 and 6.8. Values for sulfur content are 200 and 39 ppm and the copper content is 8.2 and 1.6 ppm.

According to the U.S. Bureau of Land Management (1974), chemical analyses were run at the Kerr-McGee Jacobs Ranch mine on three samples from the parting between the Upper Wyodak and Lower Wyodak 1 coal seams. All three samples were taken from a single drill hole and show little variation. The average electrical conductivity value is 0.83 mmhos/cm and the average value for cation exchange capacity is 32 meq/100 g. All of the samples are basic, with pH values of 7.9, 8.1, and 8.2. The sulfur content in all three samples is greater than 200 ppm. The average copper content is 1.57 ppm.

Explosives—

The primary potential pollutants from explosives appear to be ammonia-nitrogen, nitrate-nitrogen, fuel oil, and possibly trace organics.

Pit Discharge—

The potential pollutants in pit discharge originate from a number of sources. All of the potential pollutants from explosives can be in the pit discharge, namely, ammonium-nitrogen, nitrate-nitrogen, fuel oil, and trace organics. Most of the major inorganic chemical constituents and some trace elements can originate from groundwater percolating through the coal, overburden, and underlying beds. At the Decker Mine, in Montana, high contents of sodium, bicarbonate, and sulfate were found in pit discharge. Calcium, magnesium, chloride, boron, and fluoride are additional potential pollutants. At the Big Horn Mine, high contents of iron, manganese, zinc, and copper were found in pit discharge. Cadmium, chromium, arsenic, lead, molybdenum, vanadium, uranium, thorium, radium, and selenium are additional potential pollutants. Organic materials from the coal and related beds also comprise potential pollutants.

Gasoline and oil can be introduced by heavy equipment working in the pit. Bacteriological pollutants can be introduced from domestic wastewater, runoff, and solid wastes disposed of in or near the pits.

Supplemental Sources of Water—

As discussed in the pollution source inventory, Section 2, no pollution is anticipated from deep groundwater. The mines are using water from the deeper part of the Fort Union Formation, and quality is not a problem. Use of Fox Hills water by the City of Gillette could introduce small amounts of fluoride into shallow systems, but the relative volume of Fox Hills water used in the project area is minimal.

Imported Sewage Effluent—

The principal source of imported sewage effluent is from the City of Gillette Treatment Plant. At the present time (summer 1977) construction is being completed on a pipeline to transport effluent to the Wyodak Mine. Effluent will be delivered from two locations: (1) from the line leading into the "oxidation" pond from the aerobic digesters; and (2) from the "oxidation" pond discharge line. Wastewater imported into the Wyodak Mine will be a blend of these sources. At the present time, effluent discharged into Donkey Creek from the oxidation pond is diverted at Wyodak for road spraying. The RO unit at the Neil Simpson power plant will drastically alter the quality of effluent piped to Wyodak.

A representative analysis of wastewater from the treatment plant is not available at this time. As an approximation, the analysis on Table 3-5 was developed assuming: (1) wastewater is essentially of the same quality as incoming sewage because treatment is minimal; (2) composition of medium-strength domestic sewage reported by Metcalf and Eddy (1972) are applicable;

and (3) analysis of carrier water is similar to that for Gillette domestic water reported by Nelson et al. (1976). This latter assumption neglects infiltration/inflow (I/I) in the Donkey Creek line and changes in salt content as a result of domestic usage.

TABLE 3-5. HYPOTHETICAL QUALITY OF WASTEWATER FROM THE GILLETTE TREATMENT PLANT

Constituent	Concentration (ppm)
Suspended solids, total	200
Fixed	50
Volatile	150
BOD (5-day)	200
TOC	200
COD	200
Nitrogen (total as N)	40
Organic	15
Free ammonia	25
Nitrites	0
Nitrates	0
Phosphorus (total as P)	10
Organic	3
Inorganic	7
Alkalinity (as $CaCO_3$)	100
Grease	100
Potassium	9.5
Calcium	305
Magnesium	158
Sodium	220
Sulfate	920
Chloride	36
Bicarbonate	660
TDS	1888

The constituents and related concentrations in Table 3-5 are possibly representative of wastewater entering the "oxidation" pond from the aerobic digesters. As indicated above, this water will also be diverted to Wyodak. High total organic carbon (TOC) and chemical oxygen demand (COD) [as well as high 5-day biochemical oxygen demand (BOD)] values indicate that organics are a potential contaminant. However, during pipeline flow some additional breakdown of organics may occur. Other constituents beyond desirable limits include sulfate, nitrogen, TDS, and grease. Flow in the pipeline may be conducive to nitrification, in which case nitrite values may increase. The wastewater may contain excessive levels of coliform organisms (including fecal), viruses and other intestinal organisms.

Heavy metal concentrations may not be excessive because such metals tend to concentrate in the sludge.

Observation of the "oxidation" pond at the Gillette Treatment Plant shows that the pond actually functions as an overloaded facultative pond with operating characteristics of an anaerobic lagoon. Consequently, wastewater undergoes anaerobic digestion. According to the Missouri Basin Engineering Health Council (1971), anaerobic lagoons are capable of reducing BOD levels between 60 percent to 80 percent. However, "high concentrations of BOD, suspended solids, and sometimes hydrogen sulfide occur in the effluents depending upon the initial characteristics of the incoming wastewaters" (Missouri Basin Engineering Health Council, 1971). It is highly probably that the pond at Gillette is a poorly operating anaerobic facility. However, if the treatment effectiveness is similar to a pond in Saskatchewan (reported by the Missouri Basin Engineering Health Council, 1971), the following removal efficiencies may exist: suspended solids, 70 percent; BOD, 55 percent; COD, 60 percent; and grease, 75 percent. Using these efficiencies and the corresponding values in Table 3-5, resultant effluent concentrations may be: BOD, 90 ppm; COD, 200 ppm; and grease, 25 ppm. The chemical constituents will remain about the same, although some change in sulfate should occur due to the formation of hydrogen sulfide (H_2S). Also, because of anaerobic conditions, nitrogen constituents will remain about the same concentration. The presence of bacterial colonies floating on the surface on the pond suggests the pond effluent contains organisms such as coliform bacteria, viruses, and parasitic organisms. Reducing condition promotes the mobility of heavy metals which may have escaped the chelating effects of sludge constituents.

Since the pond effluent will be diverted to Wyodak in a pipeline, mixing will occur with wastewater diverted from the pond inlet line. Also, some decomposition will occur in the line, reducing COD and BOD (organics) somewhat and possibly promoting nitrification.

Mine Sanitary Wastes—

Septic tanks—Septic tanks reduce the BOD and solids content of sewage but not necessarily the loading of microorganisms and viruses. Discharge from a septic tank (to a leach field) contains nutrients, salts, and suspended solids. Table 3-6, reproduced from a paper by Silberman (1977), is a representative analysis of septic tank effluent concentrations. The COD and TOC values suggest that organics might be moderately high in effluent. Also note the concentration of total coliform organisms. No information is available on heavy metals, but presumably metals in the carrier water will settle with sludge in the tank or be carried out with suspended solids.

Further treatment occurs in the leaching field. Two conditions are possible: (1) if the field is overloaded and in tight soils, anaerobic conditions may result; (2) if good air circulation prevails, the leaching field will remain aerobic. The state of aeration may have an effect on sources. Aerobic conditions will increase nitrate levels in wastewater but lead to a stabilization of organics and destruction of obligate anaerobics.

TABLE 3-6. REPRESENTATIVE SEPTIC TANK EFFLUENT CONCENTRATIONS AND PERCENT REMOVED (Silberman, 1977)

Parameter	Value[a]	Percent removed or increased
pH (units)	7.1±	--
Dissolved oxygen	0	--
Biochemical oxygen demand	160	27
Chemical oxygen demand	323	47
Total organic carbon	129	46
Total phosphorus	18	40
Phosphates	34	240 increase
MBAS	7.6	67
Total solids	378	46
Total suspended solids	90	70
Total nitrogen as N	32	8
Ammonia nitrogen	27	8 increase
Organic nitrogen	8	20
Nitrate	0.14	increase
Nitrite	0.061	increase
Chlorides	95	111 increase
Alkalinity	390	225 increase
Coliforms – total (10^5/100 cc)	11-110+	--
– fecal	0.17	--

[a] Units are ppm except as noted.

Anaerobic decomposition of septic tank effluent may reduce nitrate levels (assuming that nitrification has occurred). Anaerobiosis and associated reducing conditions may lead to production of methane and hydrogen sulfide gases, carbon dioxide, and volatile compounds of mercury (Hg) and arsenic (As) (Fuller, 1977). Hydrogen sulfide (H_2S) is reactive with heavy metals as sulfides of iron (FeS), zinc (ZnS), cadmium (CdS), lead (PbS), copper (CuS), and mercury (Hg_2S or HgS). Reducing conditions increase the mobility of the majority of trace contaminants (Fuller, 1977). For example, reduced iron becomes soluble and highly mobile.

Organic acid production increases under anaerobic conditions. The resultant lowering of pH will increase the mobility of cationic heavy metals. In addition, chelation will also promote the movement of heavy metals and soluble organics.

In summary, aerobic leach fields are possible sources of nitrate, ammonia, phosphorus, potassium, chloride, any heavy metals present in abundance, organics, bacteria, and viruses. Anaerobic leach fields may also be sources of these constituents but the characteristics of the source would show the effect of anaerobic conditions on the solubility of indigenous heavy metal compounds, including those of lead, iron, manganese, copper, and mercury.

Package plants—The types and importance of potential pollutants associated with package plant effluent are the same as those for septic tanks (Todd et al., 1976). A representative analysis of effluent from package plants, reported by Silberman (1977) is shown in Table 3-7. This analysis does not include other chemical parameters which may be high in effluent, including sulfate, chloride, hardness, bicarbonate, calcium, and possibly trace metals. Viruses may also be present in the effluent.

TABLE 3-7. AEROBIC TANK EFFLUENT CONCENTRATIONS (Silberman, 1977)

Parameter	Value[a]
pH (units)	7.7
Dissolved oxygen	2.76
Biochemical oxygen demand	41
Chemical oxygen demand	158
Total organic carbon	40
Phosphates (as P)	37
Total suspended solids	57
Nitrate (as N)	8
Nitrite (as N)	2
Coliforms (10^5/100 cc)	72

[a] Units are ppm except as noted.

Operation of package plants may require the removal of solids at infrequent intervals. Solids will consist mainly of grit, with perhaps some plastic and other organic matter.

Treatment ponds—The design and operation of waste treatment ponds is such that quality varies laterally from inlet to outlet and vertically from water surface to the benthic layers. In general, the overall quality is a function of loading rate, temperature, hours of sunshine, wind action, etc. Quality is also a function of the type of pond operation, e.g., aerated pond, anaerobic pond, or facultative pond.

According to the publication, "Waste Treatment Lagoons—State of the Art," by the Missouri Basin Engineering Health Council (1971), aerated lagoons are capable of meeting the 30 ppm BOD, 30 ppm suspended solids criteria of EPA. However, aerated lagoons are not very efficient in removing nitrogen and phosphorus. The reason is that aerated lagoons operate on the principle that solids are not removed. Potential pollutants, therefore, comprise some unstabilized organics, phosphorus and nitrate, and bacteria and viruses, as well as heavy metals introduced with the raw sources. Metals will concentrate in the sludge.

Anaerobic lagoons are not normally effective for secondary treatment, and effluents could lead to pollution (Missouri Basin Engineering Health Council, 1971). Effluent quality depends on the source of wastewater, but BOD concentrations of 100 ppm to 300 ppm have been observed in anaerobic lagoon effluents from domestic sources. The ratio of discharged effluent to incoming wastewater BOD values ranges from 0.40 to 0.70. Nutrients are not appreciably reduced in anaerobic lagoons. For example, incoming organic-N and NH_4-N are not nitrified, although incoming nitrate may be denitrified.

In addition to potential pollutants within the wastewater itself, anaerobic lagoons may potentially release pollutants present in the benthic region soil. That is, anaerobic and reducing conditions may increase the solubility of cationic heavy metals in the soil. Sources related to anaerobic lagoons will include incoming nutrients and other chemical constituents (chloride, sulfate, bicarbonate, carbonate, calcium, magnesium, sodium, etc.) and organic-N, organic-P, ammonia and phosphorus compounds, bacteria, and viruses.

Facultative ponds may not attain the required standard: 30 ppm BOD, 30 ppm suspended solids, and 200 coliform per 100 cubic centimeters (cc). BOD is transformed from incoming organics into algal tissue, and suspended solids reflect algal concentrations. Algae are capable of reducing nutrients and heavy metals which, however, are released with the death and lysing of algal cells. Because of algal activity, the pH of lagoon water increases, with concomitant alteration of the bicarbonate-carbonate system. The dissolved oxygen in overlying layers may become supersaturated, while oxygen deficiency and anaerobic conditions prevail in the benthos. An abundance of dissolved oxygen (DO) in the upper part of the pond presents optimal conditions for nitrification. In addition, reactions with soil material (see above) may lead to generation of heavy metal sources. Also, under very cold or freezing conditions, such as occur in the Gillette area, facultative ponds may become anaerobic, producing sources discussed above.

For normal operation, the potential pollutants relating to facultative ponds include BOD (organics), suspended solids (organics), chemical constituents in incoming carrier water, nitrate (some of which is reduced to nitrogen gas in the benthos), a flourishing bacteria population, and viruses. In addition, heavy metals may be generated in the anaerobic and reduced benthic-soil interface.

Two mines planning to use pond pretreatment are the Wyodak mine, where an aerated sewage lagoon will be used (no data are available on expected quality) and the AMAX Belle Ayr South mine, where a "lagoon type aeration plant" will be used. The only information on quality of the pond system reported in the EIS (U.S. Department of Interior, 1975) is: "Effluent will meet...standards such as pH, iron, manganese, and TDS." A sand filter will reduce suspended solid concentrations.

Solid Wastes—

Solid waste management offers the following options:

- Onsite landfill
- Offsite disposal facility
- Incorporation in mine spoils
- Incineration followed by land disposal of residue.

Onsite landfills comprise special areas set aside on the mine specifically for landfills; offsite disposal facilities may consist of a central landfill, such as that operated by the City of Gillette; and incorporation in mine spoils is self-explanatory. Both onsite and offsite disposal facilities are centralized and allow more control. Wastes incorporated in the spoils piles will be distributed randomly, without control on the amount or nature of wastes. Incineration may create pollutants relating to flyash or gas generation as well as producing concentrated solid waste.

In general, no matter how disposed, solid wastes will contain the same potential pollutants. According to Todd et al. (1976), major types of groundwater pollutants associated with solid wastes include:

- Physical — Minor
- Inorganic chemicals — Primary
- Trace elements — Primary
- Organic chemicals — Primary
- Bacteriological — Minor
- Radiological — Minor.

Some sources present in landfills are reflected in leachates, generated by the action of water with solid wastes. The range in leachate quality, such as found in municipal landfills, is shown in Table 3-8 as reported by Pohland and Engelbrecht (1976). These authors point out that leachate is most objectionable from a pollution viewpoint when containing high concentrations of organic matter, high TDS, and low pH. Decreasing pH increases the solubility of heavy metals present in the waste. In addition, anaerobic reducing conditions in the soil-landfill interface will also dissolve indigenous heavy metals. Microbial (and virus) growth in leachate appears to be inhibited by initial elevated temperature and other inactivating properties.

The quality of leachate changes with time because of changes in composition of substrate and biological communities. Consequently, high organic concentrations in the leachate will disappear, pH will return to neutral and leachate will be less objectionable from the viewpoint of organics. Changes

TABLE 3-8. RANGE OF CHEMICAL COMPOSITION OF SANITARY LANDFILL LEACHATE (Pohland and Engelbrecht, 1976)

Constituent	Range of analyses[a]
Chemical oxygen demand	40 - 89,520
5-day biochemical oxygen demand	81 - 33,360
Total organic carbon	256 - 28,000
pH (units)	3.7 - 8.5
Total solids	0 - 59,200
Total dissolved solids	584 - 44,900
Total suspended solids	10 - 700
Specific conductance (μmho/cm)	2,810 - 16,800
Total alkalinity (as $CaCO_3$)	0 - 20,850
Total hardness (as $CaCO_3$)	0 - 22,800
Total phosphorus (as P)	0 - 130
Orthophosphorus (as P)	6.5 - 85
Ammonia nitrogen (as N)	0 - 1,106
Nitrate + nitrite (as N)	0.2 - 10.29
Calcium	50 - 7,200
Chlorine	4.7 - 2,467
Sodium	0 - 7,700
Potassium	28 - 3,770
Sulfate	1 - 1,558
Manganese	0.09 - 125
Magnesium	17 - 15,600
Iron	0 - 2,820
Zinc	0 - 370
Copper	0 - 9.9
Cadmium	< 0.03 - 17
Lead	< 0.10 - 2

[a] Values are in ppm unless otherwise noted

in inorganics are less predictable. Pohland and Engelbrecht (1976) point out the danger of extrapolating the environmental impact of leachate based on single sample analyses.

In addition to municipal-type wastes, hazardous wastes from mines may be disposed of in landfills. Information on specific hazardous wastes is not available at this time. As an initial approximation, Table 3-9 [reproduced from "Decision Makers Guide in Solid Waste Management," (U.S. Environmental Protection Agency, 1976b)] is included. This table is a sample list of non-radioactive hazardous compounds which can be considered as hazardous to public health and the environment.

Incineration followed by landfilling is an alternative waste disposal technique. Pavoni et al. (1975) review the general principles and methods employed in municipal incineration operations. Similarly, Scurlock et al. (1975) discuss requirements and precautions for incineration of hazardous wastes. Incineration releases gases and particulate matter to the atmosphere unless trapped and scrubbed. Waste gases may contain nitrogen, carbon dioxide, and water vapor. During periods of incomplete combustion, the following gases may be present: nitrogen dioxide, nitric oxide, sulfur dioxide, sulfur trioxide, and carbon monoxide (Pavoni et al., 1975). Acids or other compounds may be formed during reaction of rainwater with these gases. Chlorine containing organics may emit hydrogen chloride gas upon incineration which is highly corrosive (Scurlock et al., 1975).

Fly ash produced in municipal refuse incinerators is largely inorganic and consists of oxides of aluminum, calcium, iron, and silicon (Pavoni et al., 1975). A chemical analysis of incinerator fly ash is reproduced in Tables 3-10 and 3-11.

Incinerator residue contains soluble organic and inorganic constituents. Although a complete analysis by constituents was not presented, Pavoni et al. (1975) gave the general breakdown shown in Table 3-12. Scurlock et al. (1975) noted that organic materials may contain such heavy metals as mercury, arsenic, selenium, lead, and cadmium. These heavy metals may exist as oxides in the ash. "Landfilling of the ash...should be examined with care to ensure that health hazards or environmental degradation do not occur due to leaching of toxic metal ions to subsurface waters...." (Scurlock et al., 1975)

Fly ash may be treated with water to facilitate transportation to a final disposal site. The slurry will contain undesirable constituents, such as heavy metals. Table 3-13, reproduced from Pavoni et al. (1975), shows representative wastewater data from the incineration process.

Information on solid waste management was given for the following mines in the project area, in the associated environmental impact statements.

Solid wastes may be buried at the Kerr-McGee Jacobs Ranch mine. Possible contaminants in leachate are shown in Table 3-8.

TABLE 3-9. A SAMPLE LIST OF NONRADIOACTIVE HAZARDOUS COMPOUNDS (U.S. Environmental Protection Agency, 1976b)

Miscellaneous Inorganics
Ammonium chromate
Ammonium dichromate
Antimony pentafluoride
Antimony trifluoride
Arsenic trichloride
Arsenic trioxide
Cadmium (alloys)
Cadmium chloride
Cadmium cyanide
Cadmium nitrate
Cadmium oxide
Cadmium phosphate
Cadmium potassium cyanide
Cadmium (powdered)
Cadmium sulfate
Calcium arsenate
Calcium arsenite
Calcium cyanides
Chromic acid
Copper arsenate
Copper cyanides
Cyanide (ion)
Decaborane
Diborane
Hexaborane
Hydrazine
Hydrazine azide
Lead arsenate
Lead arsenite
Lead azide
Lead cyanide
Magnesium arsenite
Manganese arsenate
Mercuric chloride
Mercuric cyanide
Mercuric diammonium chloride
Mercuric nitrate
Mercuric sulfate
Mercury
Nickle carbonyl
Nickle cyanide
Pentaborane-9
Pentaborane-11
Perchloric acid (to 72%)
Phosgene (carbonyl chloride)
Potassium arsenite
Potassium chormate
Potassium cyanide
Potassium dichromate
Selenium
Silver azide
Silver cyanide
Sodium arsenate
Sodium arsenite
Sodium bichromate
Sodium chromate
Sodium cyanide
Sodium monofluoroacetate
Tetraborane
Thallium compounds
Zinc arsenate
Zinc arsenite
Zinc cyanide

Halogens and Interhalogens
Bromine pentafluoride
Chlorine
Chlorine pentafluoride
Chlorine trifluoride
Fluorine
Perchloryl fluoride

Miscellaneous Organics
Acrolein
Alkyl leads
Carcinogens (in general)
Chloropicrin
Copper acetylide
Copper chlorotetrazole
Cyanuric triazide
Diazodinitrophenol (DDNP)
Dimethyl sulfate
Dinitrobenzene
Dinitro cresols
Dinitrophenol
Dinitrotoluene
Dipentaerythritol hexanitrate (DPEHN)
GB (propoxy (2)-methylphosphoryl fluoride)
Gelatinized nitrocellulose (PNC)
Glycol dinitrate
Gold fulminate
Lead 2,4-dinitroresorcinate (LDNR)
Lead styphnate
Lewisite (2-chloroethenyl dichloroarsine)
Mannitol hexanitrate
Nitroaniline
Nitrocellulose
Nitrogen mustards (2,2',2" trichlorotriethylamine)
Nitroglycerin
Organic mercury compounds
Pentachlorophenol
Picric acid
Potassium dinitrobenzfuroxan (KDNBF)
Silver acetylide
Silver tetrazene
Tear gas (CN)(chloroacetophenone)
Tear gas (CS)(2-chlorobenzylidene malononitrile)
Tetrazene
VX (ethoxy-methyl phosphoryl N,N dipropoxy-(2-2), thiocholine)

Organic Halogen Compounds
Aldrin
Chlorinated aromatics
Chlordane
Copper acetoarsenite
2,4-D(2,4-dichlorophenoxyacetic acid)
DDD
DDT
Demeton
Dieldrin
Endrin
Ethylene bromide
Fluorides (organic)
Guthion
Heptachlor
Lindane
Methyl bromide
Methyl chloride
Methyl parathion
Parathion
Polychlorinated-biphenyls (PCB)

TABLE 3-10. CHEMICAL ANALYSIS OF INCINERATOR FLY ASH
(Pavoni et al., 1975)

Component	Gansevoort incinerator, New York City[a] (% by weight)	South Shore incinerator, New York City[a] (% by weight)	Arlington, VA[a] (%)	Jens-Rehm study[b] (%)	Kaiser study[c] (%)
Carbon					
Organic	14.5	10.4	11.62	-	-
Inorganic	85.5	89.6	-	-	-
Silicon as SiO_2	36.0	36.1	-	-	36.3
Si	-	-	18.64	5+	-
Aluminum as Al_2O_3	27.7	22.4	-	-	25.7
Al	-	-	10.79	1-10	-
Iron as Fe_2O_3	10.0	4.2	-	-	7.1
Fe	-	-	2.13	0.5-8.0	-
Sulfur as SO_3	9.7	7.6	Small or trace	-	8.0
S	-	-		-	-
Calcium as CaO	8.5	8.6	-	-	8.8
Ca	-	-	4.70	1.0+	-
Magnesium as MgO	3.4	2.1	-	-	2.8
Mg	-	-	0.98	1-10	-
Titanium as TiO_2	-	-	-	-	0.9
Ti	-	-	2.24	0.5-5.0	-
Ni	-	-	Small or trace	1-10	-
Na	-	-	Small or trace	1-10	-
Zn	-	-	Small or trace	1-10	-
Ra	-	-	Small or trace	0.1-1.0	-
Cr	-	-	Small or trace	0.1-1.0	-
Cu	-	-	Small or trace	0.1-1.0	-
Mn	-	-	Small or trace	0.1-1.0	-
Sn	-	-	Small or trace	0.05-0.5	-
B	-	-	-	0.01-0.1	-
Pb	-	-	Small or trace	0.01-0.1	-
Be	-	-	-	0.001-0.01	-
Ag	-	-	Small or trace	0.001-0.01	-
V	-	-	-	0.001-0.01	-

Sources:

[a] Municipal Refuse Disposal. Inst. for Solid Wastes, Amer. Public Works Assn., 1970.

[b] Jens, W., and F.R. Rehm. Municipal Incinerator and Air Pollution Control. Proc. Nat'l. Incin. Conf., Amer. Soc. Mech. Eng., 1966, p. 74.

[c] Kaiser, E.R. Refuse Composition and Flue-Gas Analyses from Municipal Incinerators. Proc. Nat'l. Incin. Conf., Amer. Soc. Mech. Eng., 1964, p. 35.

TABLE 3-11. CHEMICAL ANALYSIS OF INCINERATOR FLY ASH (Pavoni et al., 1975)

Component	Gansevoort incinerator, New York City[a] (% by weight)	South Shore incinerator, New York City[a] (% by weight)	Arlington, VA[a] (%)	Kaiser study[b] (%)
Sodium and potassium oxides	4.7	19.0	-	-
Na as Na_2O	-	-	-	10.4
Na	-	-	Small or trace	-
K	-	-	Small or trace	-
Ga	-	-	Small or trace	-
Hg	-	-	Small or trace	-
Mo	-	-	Small or trace	-
Ta	-	-	Small or trace	-
Apparent specific gravity	2.58	-	-	-
Ignition loss	-	-	14.45	-

Sources:

[a] Municipal Refuse Disposal. Inst. for Solid Wastes, Amer. Public Works Assn., 1970.

[b] Kaiser, E.R. Refuse Composition and Flue-Gas Analyses from Municipal Incinerators. Proc. Nat'l. Incin. Conf., Amer. Soc. Mech. Eng., 1964, p. 35.

TABLE 3-12. INCINERATOR RESIDUES (Pavoni et al., 1975)

Material	Washington, D.C.,[a] Metro-Average grate-type municipal incinerators (% dry weight)	Rotary-kiln incinerator[b]
Tin cans	17.2	19.3 + 6.5 (nonmetallics)
Mill scale and small iron	6.8	10.7
Iron wire	0.7	0.5
Massive iron	3.5	1.9
Nonferrous metals	1.4	0.1
Stones and bricks	1.3	-
Ceramics	0.9	0.2
Unburned paper and charcoal	8.3	3.4 (charcoal)
Partially burned organics	0.7	-
Ash	15.4	57.0
Glass	44.1	-

Sources:

[a] Kenahan, C.B., and P.M. Sullivan. Let's Not Overlook Salvage. AWPA Rep., Vol. 34, No. 3, 1967, p. 5.

[b] Rampacek, G. Reclaiming and Recycling Metals and Minerals Found in Municipal Incinerator Residues. Proc., Mineral Waste Utilization Symp., March 27-28, 1968, LLT Research Institute, p. 129.

TABLE 3-13. INCINERATOR WASTEWATER DATA (Pavoni et al., 1975)

Characteristic	Plant 1			Plant 2		
	max.	min.	avg.	max.	min.	avg.
pH	11.6	8.5	10.4	11.7	6.0	10.5
Diss. solids, ppm	9,005	597	3,116	7,897	1,341	4,283
Susp. solids, ppm	2,680	40	671	1,274	7	372
Total solids, % volatile	53.6	18.5	36.3	51.6	10.5	31.2
Hardness ($CaCO_3$), ppm	1,574	216	752	1,370	112	889
Sulfate (SO_4), ppm	430	110	242	780	115	371
Phosphate (PO_4), ppm	55.0	0.0	23.3	212.5	1.0	23.5
Chloride (C), ppm	3,650	50	627	2,420	76	763
Alkalinity ($CaCO_3$), ppm	1,250	2.5	516	1,180	292	641
5-day BOD @ 20° C	--	--	--	--	--	--

Characteristic	Plant			Plant 6		
	max.	min.	avg.	max.	min.	avg.
pH	6.5	4.8	5.8	4.7	4.5	4.6
Diss. solids, ppm	1,364	7,818	8,838	6,089	5,660	5,822
Susp. solids, ppm	398	208	325	2,010	848	1,353
Total solids, % volatile	--	--	--	24.69	23.26	23.75
Hardness ($CaCO_3$), ppm	2,780	2,440	2,632	3,780	3,100	3,437
Sulfate (SO_4), ppm	1,350	1,125	1,250	862	625	725
Phosphate (PO_4), ppm	15.0	11.5	13.0	76.2	32.2	51.5
Chloride (C), ppm	3,821	3,077	3,543	2,404	2,155	2,297
Alkalinity ($CaCO_3$), ppm	28	16	23	4	0	1.33
5-day BOD @ 20° C	13.5	6.2	8.8	--	--	--

Sources:

Plants 1 and 2, USPHS Report on the Municipal Solid Wastes Incinerator System of the District of Columbia, 1967.

Plants 5 and 6, USPHS unpublished data (SW-11ts) (SW-12ts).

Plant 1 - 110 TPD[a] Residue Quench (Batch).
Plant 2 - 125 TPD Residue Quench (Batch).
Plant 5 - 200 TPD Cont. Feed-Flyash Effluent.
Plant 6 - 300 TPD Cont. Feed-Flyash Effluent.

[a] TPD = tons per day

Inert sludge from the package plant at the Sun Oil Cordero mine will be buried in topsoil and graded in the spoil. Sludge may contain concentrated levels of trace metals due to the affinity of metals to organics (Council for Agricultural Science and Technology, 1976). Possible metals may include: manganese, iron, aluminum, chromium, arsenic, selenium, antimony, lead, mercury, cadmium, copper, molybdenum, nickel, and zinc (Council for Agricultural Science and Technology, 1976).

Ash produced by incineration at the Wyodak mine will be interlayered with overburden and buried. Potential contaminants are shown in Tables 3-12 and 3-13. Solid wastes will also be buried, and potential pollutants in leachate are listed in Table 3-8.

Reclaimed Area Sources

Fill Materials—

The pollution potential of the fill materials, topsoil, and spoils has been discussed previously in the subsection "Stockpiles." The chemistry and amount of pollutants dissolved from the topsoil and spoils during movement of water through these materials will depend on the locations of the various subcategories of these materials replaced within the mined area and their relation to the modified hydrogeologic system that exists after mining. The maximum available quantities of soluble salts and trace metals can be estimated, as has been indicated, but the potential mobility of the trace elements and rates of dissolution of the soluble salts and trace metals from topsoils have not been defined.

Spoil will consist of a heterogeneous mixture of overburden material originally present in the indigenous vadose zone and shallow aquifer systems. Overburden consists of sandstone, shale, and thin or impure coal beds of the Wasatch or uppermost Fort Union Formations. Scoria, or baked shale and siltstone may also be present, together with alluvial material. Partings or coaly wastes above or between coal beds may constitute potential sources of pollution at many sites. Some parting materials have been found with pH values in the acidic range and containing high concentrations of certain constituents. As an example, analyses of three grab samples of overburden material are shown in Table 3-14, as reported by McTernan (1974). Samples I and II were sandy loam and Sample III was a silty clay loam ("Blue-Shale"). Compared to Samples I and II, the silty clay loam had a low pH, 3.9, and higher concentrations of sulfur, iron, copper, and magnesium. The low pH is of significance in that heavy metals become more soluble in the acidic range. In controlled laboratory experiments, McTernan observed the bacterial oxidation of sulfur with a subsequent increase of pH to about 6.3. After about 50 days, pH values once again decreased.

Several of the mine environmental impact statements indicate that clay partings will be buried in the spoil piles, i.e., below the reclaimed soil zone. Such a procedure will position potential sources of pollution within the vadose zone.

TABLE 3-14. CHEMICAL AND PHYSICAL DATA: THREE OVERBURDEN GRAB SAMPLES (McTernan, 1974)

Characteristic	Sample I	Sample II	Sample III (blue-shale)
Sulfur (ppm)	70	630	1,200
Iron (ppm)	5.1	4.2	46
Copper (ppm)	0.6	0.3	722
Calcium (ppm)	1,900	1,500	1,400
Magnesium (ppm)	330	310	670
NO_3 (ppm)	2.0	3.0	2.0
pH	8.1	8.1	3.9
Texture	Sandy loam	Sandy loam	Silty clay loam

In addition to partings, isolated lenses of precipitated gypsum (e.g., as selenite) or marcasite (iron sulfide) have been observed. Tait (1976), for example, noted the presence of both gypsum and marcasite within fractures of coal aquifers on the Coal Creek property of ARCO. Relatively pure specimens of selenite have been observed on the sides of a landfill trench, near the City of Gillette.

The vadose zone developed within spoil piles will include the following potential sources: (1) sources exposed on fresh surfaces of replaced overburden; (2) sources on layers of compacted partings, coaly wastes, or toxic strata; and (3) sources within buried solid wastes.

In his studies of strip-mine spoils in the Powder River Basin, Rahn (1976) observed that samples of water from spoils are significantly more concentrated in total salt than native groundwater. Particularly high concentrations of calcium and sulfate were observed. He attributed increased salt content to the dissolution of salts exposed on the spoils blocks. Calcium and sulfate levels were high because of the presence of gypsum crystals — gypsum is the most soluble of exposed salts. High concentrations of magnesium were also observed. Manganese was high in most samples examined by Rahn (1976), possibly reflecting the weathering of pyrolusite or psilomelane. Excessive levels of sodium were noted in some samples. The pH values of spoil water samples were generally in the alkaline range.

Specific pollutants related to solid wastes (including sludge) buried within the modified vadose zone are discussed elsewhere. In summary, leachate generated in such wastes could run the gamut from hazardous substances to excessive concentrations of heavy metals.

Environmental impact statements for several of the mine sites indicate that parting material, coaly wastes, or toxic strata will be buried within the spoils. The major pollutants in these layered-in deposits are heavy metals — although high concentrations of calcium sulfate may also be present. These layers may be more compacted than the overlying spoil, possibly leading to the formation of perched water tables following surface flooding. Anaerobic conditions brought about by the water table conditions may have an influence on heavy metals movement.

In particular, the following effects may occur:

- Reducing conditions may increase the mobility of cationic heavy metals. That is, "...trace contaminants arsenic, beryllium, chromium, copper, iron, nickel, selenium, vanadium, and zinc are much more mobile under anaerobic soil conditions, all other factors the same" (Fuller, 1977)
- Reducing conditions lead to the formation of hydrogen sulfide and consequently heavy metal sulfides. These metals are relatively insoluble.

Since these two factors are counteractive, the net movement of metals may be hard to predict. Other conditions should also be taken into account. For example, partings from several mine sites have low pH values. Metals are more mobile in the acid range (Fuller, 1977). However, the pH of partings may change before being inundated, particularly if an organic source of energy is available for bacteria capable of oxidizing sulfur (McTernan, 1974).

The EIS for the Belle Ayr South mine indicates high values of organic copper, zinc, and selenium in overburden samples. In addition, certain sample profiles disclosed higher EC and SAR values within the upper five feet. Table 3-14 (McTernan, 1974) includes analyses from three overburden samples. Obviously, Sample III (blue-shale) contained the highest concentrations of sulfur, iron, copper, and magnesium. The pH for Sample III was 3.9.

Analyses of saturation extracts from sample holes at the Eagle Butte mine site showed high values for both chloride and sulfate. Regarding heavy metals in overburden, the EIS stated: "There exists no definable trend of trace metals within the overburden... For all overburden samples, cadmium (Cd) values range from a minimum 0.03 ppm to a maximum 0.85 ppm and average 0.174 ppm. Mercury (Hg) ranges from 1.63 ppm to 51.63 ppm... With exception of 16 samples which possess measured lead concentrations ranging from 1.056 to 2.96 ppm, all remaining samples disclose concentrations less than 1 ppm. For all samples, lead (Pb) concentrations range from 0.003 to 2.96 ppm and average 0.43 ppm." Since native soils normally contain between 40 and 70 ppm lead (Fuller, 1977), these values are not excessive. One sample of partings contained a pH of 4.5.

Drever et al. (1977) reported that heavy metals were strongly enriched near the margins of coal seams at the Black Thunder mine. Table 3-15, reproduced from their report, illustrates relative magnitudes of heavy metals and sulfur in the overburden core samples. Note the concentration of metals between 77 and 79 feet. Relative to the other core samples, samples in this range contained high levels of arsenic, cadmium, calcium, mercury, molybdenum, lead, uranium, and sulfur. Table 3-16 compares average trace metal concentrations from cores at the Black Thunder mine with values for average U.S. coal, average shale, and Okefenokee peat. The upper interface region contained higher values of beryllium, calcium, lead, and uranium than other samples. However, Drever et al. (1977) pointed out that "...the trace element concentrations in the interface region are not outstandingly high in comparison to average shale or coal."

TABLE 3-15. TRACE ELEMENT CONTENT OF COAL AND ASSOCIATED ROCKS, CORE BT249 (coal analyses reported on whole coal basis)(Drever et al., 1977)

Layer	Depth (feet)	As (ppm)	Be (ppm)	Cd (ppm)	Cu (ppm)	Hg (ppm)	Mo (ppm)	Pb (ppm)	U (ppm)	S (%)	Ash (%)
Overburden											
	10	<0.05	5	<4	25	0.10	5	33	-	-	-
	13	0.13	4	<4	15	0.13	<4	30	-	-	92.3
	16	<0.05	4	<4	13	0.03	<4	20	-	-	94.8
	19	<0.05	3	<4	11	0.03	6	30	2	-	96.5
	22	<0.05	4	<4	12	0.04	<4	30	-	-	-
	25	<0.05	3	<4	15	0.04	<4	30	-	-	95.7
	27	0.08	6	<4	21	0.23	6	35	3	-	92.3
	32	<0.05	6	<4	18	0.11	<4	50	-	-	-
	33	0.08	5	<4	21	0.18	<4	35	-	-	92.2
	36	0.45	5	<4	20	0.14	5	50	-	-	92.2
	39	0.13	3	0.5	10	0.06	5	30	-	-	-
	42	<0.05	<2	0.2	8	<0.02	<4	20	2	-	97.5
	45	0.30	5	<4	14	0.09	5	30	-	-	88.2
	48	0.60	4	<4	30	0.10	5	23	-	-	-
	51	0.40	5	<4	25	0.10	6	28	3	-	91.4
	54	0.40	4	<4	24	0.08	5	33	-	-	93.5
	57	0.55	5	<4	25	-	5	32	4	-	89.9
	60	2.5	5	<4	27	0.02	8	31	5	-	90.7
	63	-	5	<4	20	<0.02	<4	32	5	-	89.6
	65	1.0	4	<4	25	0.10	5	25	-	-	93.4
	70	0.35	3	<4	15	0.15	6	40	-	-	93.1
	73	7.5	<2	<4	14	0.04	7	30	-	-	96.7
	76	4.0	10	<4	70	0.05	20	100	5	0.25	85.0
	76	0.60	11	<4	63	-	10	73	6	0.22	69.8
	77.3	0.50	7	10	72	1.07	23	100	11	0.44	45.2
	77.3	0.25	6	<3	43	0.02	<20	55	6	0.03	85.3
	78.3	0.63	10	6	120	-	<20	145	9	0.15	85.4
Overburden											
	78.6	0.78	20	<4	54	0.66	54	46	12	1.03	39.9
Coal seam											
	78.6	1.0	3.6	2.0	26	0.37	5.3	19	3	0.89	13.2
	82	0.02	0.5	<0.3	7.4	0.06	<2	5.8	0.06	0.63	5.3
	92	0.02	0.48	<0.4	9	0.06	<2	6	0.35	0.51	5.4
	100	0.02	0.14	<0.4	12	0.05	<2	7	0.26	0.48	4.2
	106	0.04	0.15	<0.4	6	0.05	<2	5	0.16	0.32	3.8
	114	<0.1	0.2	<0.4	8.3	0.06	<1	4.3	0.41	0.35	4.5
	120	0.09	0.26	<0.4	4	0.02	<1	5	0.15	0.26	4.4
	128	0.07	0.09	<0.4	3	0.05	<2	4	0.06	0.24	2.8
	136	0.02	0.28	<0.4	5	0.04	<2	5	0.12	0.25	3.8
	146	0.15	0.3	<0.4	4.5	0.04	<1	4.5	0.10	0.52	4.5
Coal seam											
	149	0.20	1.9	0.05	83	0.05	4.1	21	4	0.46	11.9
Floor											
	149	<0.1	6	<4	55	<0.02	<20	80	4	0.03	83.2
	151.5	1.1	5	<2	58	0.47	9	69	5.3	0.44	43.1
	152	0.15	8	<4	33	<0.02	<20	80	-	0.01	89.1
	153.5	0.35	9	<4	33	0.08	<20	100	6	-	90.7
	153.5	0.54	4	<2	25	-	9	36	2	-	44.5
	154.5	1.6	11	<2	48	2.0	27	47	6	-	26.7
	156.5	0.37	9	<2	35	0.48	20	38	12	-	31.9
	157	0.09	11	<4	160	0.49	<20	120	-	-	70.0
	158.3	1.0	7	<4	75	0.78	15	60	-	-	50.5
	159.5	-	8	0.3	30	-	<20	80	-	-	92.1

TABLE 3-16. COMPARISON OF AVERAGE TRACE ELEMENT CONCENTRATIONS (ppm)
(Drever et al., 1977)

Sample	Be	Cu	Mo	Pb	As	Hg	U
Coal seam *excluding margins*	0.3	6.6	1	5	0.05	0.05	0.2
Upper interface region	11	70	21	87	2.5	0.3	8
Average U.S. coal	1.6	15	7.5	35	14	0.2	4.0
Average shale	3	45	2.6	20	13	0.4	3.7
Okefenokee peat	-	25	-	13	-	0.4	-

Analyses of overburden, included in the EIS for the Rawhide Mine, clearly show that partings between coal seams have low pH values and sometimes high concentrations of heavy metals. Table 3-17, reproduced from the EIS from the Rawhide Mine, illustrates that a low pH value of 4.9 was reported for partings in hole NRH-76C (202-212.4 feet). Relative to some other samples, the concentrations of zinc, iron, and molybdenum were higher in the sample from NRH-76C.

Data on specific pollutants at the Kerr-McGee Jacobs Ranch Mine site are limited. There are no reported seams in the overburden with low pH values. High concentrations of calcium, magnesium, and sulfur were present in a reported analysis.

The EIS for the Cordero Mine states that no significant amounts of toxic substances have been found in either the topsoil or overburden analyses and none is anticipated. Despite this statement, results of analyses of overburden samples in the Mining and Reclamation Plan illustrate some samples had low pH values. For example, the sample from 19 to 21 feet at location 75-14-2 had a pH of 4.5 and higher than normal levels of phosphorus, nitrate nitrogen, iron, and cadmium.

OIL AND GAS EXTRACTION

Potential groundwater pollutants derived from oil and gas extraction include oil, from casing leaks, surface leaks and spills, and seepage from the mud pit; nitrates from incomplete explosions in shot holes; bentonite and organics from drilling muds such as Revert; salts from brines and formation waters encountered during drilling; and hydrocarbons, which have fallen to the ground from atmospheric emissions.

CONSTRUCTION

Construction waste is usually solid waste, and is disposed of in landfills at the mine or in the Gillette Landfill. Landfill pollutants are discussed under municipal sources. Some of these pollutants come from decomposing and/or disassociating construction wastes.

Pollutants introduced by construction include, but are not limited to, the following:

TDS
Calcium
Iron
Copper
Zinc
Chromium
Manganese
Chloride
Sulfate
COD
BOD
pH (acid generation)
Oil and grease
(Other trace metals)

The above list includes the most common contaminants introduced by deterioration of construction wastes. An exact appraisal of the pollutants generated would require a detailed listing of discarded material.

TABLE 3-17. ANALYSES OF OVERBURDEN MATERIALS (U.S. Geological Survey, 1974b)

Hole No.	Depth of sample (ft)	Sample description	pH		CEC (meg/ 100 g)	Salt (mmhos/ cm)	Na (meg/ 100 g)	Lime (%)	Organic matter (%)	Available nutrients (ppm)											
			H_2O	Salt						NO_3	NH_4	P	K	Ca	Mg	S	B	Zn	Fe	Mn	Cu
NRH-45C	24-34	Silty clay (overburden)	8.1	7.7	25	1.3	0.9	6.7	0.8	29	1.2	2.0	210	2500	1000	180	0.6	1.7	13	7.0	2.1
NRH-46C	7-14	Clay (overburden)	8.2	7.5	20	0.7	0.5	0.3	0.9	1.0	0	68	150	2100	720	62	1.3	1.7	50	0.5	6.6
NRH-76C	111.5-119.5	Silty clay loam (overburden)	8.3	7.8	15	1.0	0.5	3.1	0.6	9.0	0.3	1.0	140	1700	410	160	0.4	3.3	16	3.2	0.7
NRH-76C	119.5-121.4	Silty clay	8.7	8.0	15	0.7	0.5	3.7	0.6	11	0.3	1.0	130	1700	410	180	0.6	3.9	15	3.5	0.3
NRH-76C	204-212.4	Silty clay (parting between coal seams)	4.9	4.7	73	2.4	1.1	0	5.5	3.0	0.8	1.0	270	2600	790	200	4.8	7.8	50	7.0	8.2
NRH-79C	51-59	Silty clay loam (overburden)	7.5	7.4	31	4.2	0.6	2.4	0.8	10	0.4	1.0	160	3900	1100	200	0.3	0.6	18	2.1	0.4
NRH-79C	59-62	Silty clay loam (overburden)	7.6	7.5	33	4.2	0.6	1.7	1.3	16	1.0	1.0	160	3800	1400	200	0.2	3.0	10	0.6	1.2
NRH-92C	31-43	Sandy clay (overburden)	8.1	7.9	24	2.4	0.6	7.9	0.5	4.0	0.1	1.0	160	3200	630	200	0.3	0.9	8.8	2.9	0.2
NRH-98C	30-40	Silty clay (overburden)	8.0	7.8	25	2.4	1.2	5.0	1.6	4.0	0.3	1.0	270	2900	790	200	0.3	2.2	14	6.3	2.2
NRH-99C	120-130	Silty clay loam (overburden)	8.3	7.9	19	1.3	1.1	7.7	1.5	10	0.8	2.0	270	2000	620	200	0.3	2.5	37	4.8	1.1
NRH-112C	45-55	Silty clay (overburden)	8.5	7.9	21	0.8	1.6	5.8	2.2	4.0	0.4	3.0	340	2000	660	62	0.2	3.8	40	11	0.7
NRH-112C	129-137.3	Clay (overburden)	7.4	7.1	13	1.7	1.2	0.5	4.6	1.0	0.2	1.0	280	1300	460	200	0.5	20	46	10	3.2
NRH-126C	171-178.5	Silty clay loam (parting between coal seams)	6.8	6.2	11	0.8	1.0	0	4.1	1.0	0.2	1.0	240	860	380	39	0.7	1.6	31	2.0	1.6

COAL CONVERSION

Steam Electric Power Plants

Analyses are available for atmospheric emissions and fly ash from the existing power plant. Potential pollutants from packaged sewage treatment plants of the type that the power plant will employ are discussed in another section.

The major pollutants found in atmospheric emissions are sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and particulates.

Sulfur dioxide in the flue gas is produced by oxidation of sulfur in the coal. Some of the sulfur is recovered as pyrites, and some of the sulfur dioxide formed is removed from the flue gas after reacting with alkaline fly ash. At this time, it is not anticipated that wet scrubbers for sulfur removal will be required to meet State and Federal air quality standards; however, provisions have been made for the addition of scrubbers should they become necessary. On the basis of an average sulfur content in coal of 0.50 percent and about 4 percent sulfur removal in the furnace, SO_2 emissions from the new unit will be less than the allowable limit of 1.2 pounds per million Btu of heat input. Tests on Unit 5 show greater than 30 percent sulfur removal.

Nitrogen oxides (NO_x) are formed by oxidation of nitrogen in the combustion of air and fuel, a process which is influenced by firing conditions in the boiler. NO_x emissions from the boiler in the new plant are guaranteed by the boiler manufacturer not to exceed 0.7 pound of NO_x per million Btu of heat input.

Table 3-18(a) shows expected operating conditions for 100 percent load and predicted emissions from both existing Unit 5 and the new plant. Table 3-18(b) shows peak ground level concentrations of sulfur dioxide, nitrogen dioxide, and particulates from the existing plant, while Table 3-18 (c) shows predicted ground level concentrations for the new plant together with Unit 5. Table 3-18(d) gives an analysis of the projected ash from Unit 5 of the existing power plant.

Gasification

The potential pollutants associated with the Hoe Creek in situ coal gasification experiment are related to the water quality of the aquifers of the area, nature of explosives used in fracturing, and material created or released during the gasification burn. Pollutants associated with hydrologic-geologic exploration, placement of experimental wells, and dewatering are related to aquifer water quality which is described in Section 6 (Existing Groundwater Quality). Characteristics of explosives used are unknown at this time but they could create pollutants associated with fracturing of the coal seam and dewatering of the fractured zone. The gasification process itself is the major potential pollution source. Descriptions of possible pollutants follow.

Containment of potential pollutants produced as gasification byproducts may be a major problem of in situ processing. Principal pollutants expected

TABLE 3-18(a). PREDICTED OPERATING CONDITIONS AND EMISSIONS FROM UNIT 5 AND THE NEW PLANT UNDER 100 PERCENT LOAD (Black Hills Power and Light Co., 1973)

Parameters	Unit 5	New plant
Fuel rate (lb/h)	32,000	440,000
Flue gas rate (lb/h)	295,400	4.07 million
Heating value (Btu/h)	8,255	8,255
Heat input (Btu/h)	266 million	3.6 billion
Predicted emissions (lb/h)		
SO_2	320	4,240
NO_2	288	2,526
Particulates	90	281

TABLE 3-18(b). PEAK GROUND LEVEL CONTAMINANTS FROM EXISTING PLANT (Black Hills Power and Light Co., 1973)

Contaminants	Peak concentration	Wyoming standard	Federal primary standard
SO_2			
3-h avg	0.233 ppm	0.5 ppm	
24-h avg	0.055	0.1	0.14 ppm
Annual avg	0.0049	0.02	0.03
NO_2			
Annual avg	0.0056 ppm	0.05 ppm	0.05 ppm
Particulates			
24-h avg	309.1 $\mu g/m^3$	150 $\mu g/m^3$	260 $\mu g/m^3$
Annual avg	29.5	60	75

TABLE 3-18(c). PREDICTED COMBINED GROUND LEVEL POLLUTANT CONCENTRATIONS FROM NEW PLANT AND EXISTING UNIT 5 (Black Hills Power and Light Co., 1973)

Contaminants	Peak concentration	Federal 2° standard
SO_2		
3-h avg	0.078 ppm	0.5 ppm
24-h avg	0.0109	0.10
Annual avg	0.0007	0.02
NO_2		
Annual avg	0.0006 ppm	0.05 ppm
Particulates		
24-h avg	10.61 $\mu g/m^3$	150 $\mu g/m^3$
Annual avg	0.73	60

TABLE 3-18(d). PROJECTED CONSTITUENTS OF ASH FROM THE NEW PLANT AND EXISTING UNIT 5 (Black Hills Power and Light Co., 1973)

Compound	Percent
Phosphorus pentoxide	0.9
Silica	39.5
Ferric oxide	6.3
Alumina	22.6
Titania	1.4
Lime	21.4
Magnesia	5.3
Sulfur trioxide	0.7
Potassium oxide	0.5
Sodium oxide	0.7
Undetermined	0.7

are hydrogen sulfide, ammonia, hydrogen cyanide, phenols, benzenes, and oils. High levels of dissolved salts (including chlorides and fluorides) may also be released from the coal reaction. Results of analysis of byproduct water from synthane gasification (a surface process) are shown in Table 3-19. These data may be representative of in situ byproducts.

The indicated high levels of organic matter in byproduct water may contain a variety of compounds:

- Tar (phenols, cresols, pyridines, anilines, catechols)
- Intermediate and high boiling point aromatics (e.g., naphthalenes)
- Saturates
- Olefins
- Thiophenes
- Light oil and/or naphtha, BTX (benzene-toluene-xylene), naphthalene, thiophene, condensed light hydrocarbons, and disulfide carbon.

Organic compounds tentatively identified in pilot plant studies are phenol, o and m cresol, dimethylphenol (2,4; 2,5; 2,6; 3,4), α naphthol, and 1,2 dihydronaphthalene. Results of benzene-soluble tars produced as gasification byproducts are shown in Table 3-20. Coke oven tars are known to contain relatively high levels of carcinogenic organic compounds. Considering that coke ovens operate in the same temperature range as some gasification processes (although at lower pressures than surface gasifiers), similar products may be formed during coal gasification.

The trace compounds which may be formed during coal gasification have been extensively evaluated. Many of the compounds potentially formed are organometallic compounds, such as:

- metal-porphyrins
- metal-carbonyls
- metallocenes
- arene carbonyls
- metal alkyls
- organohydrides
- metal chelates.

The biological origin of coal makes it likely that porphyrin compounds are present. Porphyrins are known to bind metals such as vanadium and nickel. High partial pressures of carbon monoxide may lead to metal-carbonyl formation (e.g., carbonyls of nickel, iron and cobalt). These toxic compounds are unstable at high temperatures but trace amounts may be produced. Metallocenes of iron, nickel, chromium, vanadium, tantalum, molybdenum, and tungsten may be formed. Carbon monoxide pressure may also enhance formation of arene carbonyls which are more stable than metallocenes and hence may be common species. Although metal alloys are generally unstable, they may be important in the mobility of trace metals in the gasification zone. Stable organohydrides of lead, tin, germanium and silica may be formed in the reducing gasification environment. Metal chelates formed from phenolics, carboxylic acids and amino groups may be important to the mobilization and release of metals.

TABLE 3-19. BYPRODUCT WATER ANALYSIS FROM SYNTHANE GASIFICATION OF VARIOUS COALS (Jones et al., 1977)

Water constituent[c]	Coke plant	Illinois no. 6 coal	Wyoming sub-bituminous coal	Illinois char	North Dakota lignite	Western Kentucky coal	Pittsburgh seam coal
pH	9	8.6	8.7	7.9	9.2	8.9	9.3
Suspended solids	50	600	140	24	64	55	23
Phenols	2,000	2,600	6,000	200	6,600	3,700	1,700
COD	7,000	15,000	43,000	1,700	38,000	19,000	19,000
Thiocyanate	1,000	152	23	21	22	200	188
Cyanide	100	0.6	0.23	0.1	0.1	0.5	0.6
Ammonia	5,000	8,100[a]	9,520	2,500	7,200	10,000	11,000
Chloride	--	500	--	31	--	--	--
Carbonate	--	6,000[b]	--	--	--	--	--
Bicarbonate	--	11,000[b]	--	--	--	--	--
Total sulfur (SO_4)	--	1,400	--	--	--	--	--

[a] 85 percent free NH_3

[b] Not from same analysis

[c] Units ppm except for pH

TABLE 3-20. MASS SPECTROMETRIC ANALYSIS OF BENZENE-SOLUBLE TARS (units are percent by volume) (Jones et al. 1977)

Structural type	Illinois No. 6 coal[a]	Lignite	Montana sub-bituminous coal	Pittsburgh coal
Benzenes	2.1	4.1	3.9	1.0
Indenes	8.6[b]	1.5	2.6	6.1[b]
Indains	1.9	3.5	4.9	2.1
Naphthalenes	11.6	19.0	15.3	16.5
Fluorenes	9.6	7.2	9.7	10.7
Acenaphthenes	13.5	12.0	11.1	15.8
3-ring aromatics	13.8	10.5	9.0	14.8
Phenylnaphthalenes	9.8	3.5	6.4	7.6
4-ring pericondensed	7.2	3.5	4.9	7.6
4-ring catacondensed	4.0	1.4	3.0	4.1
Phenols	2.8	13.7	5.5	3.0
Naphthols	( )[b]	9.7	9.6	( )[b]
Indanols	0.9	1.7	1.5	0.7
Acenaphthenols	--	2.5	4.6	2.0
Phenatheols	2.7	--	0.9	--
Dibenzofurans	6.3	5.2	5.6	4.7
Benzongohthothiophenes	1.7	--	--	--
B-heterocyclics[c]	10.8	3.8	5.3	8.8
Average molecular weight	212	173	230	202

[a] Spectra indicates traces of 5-ring aromatics

[b] Includes any naphthol present (not resolved in these spectra)

[c] Data on N-free basis since isotope corrections were estimated

Because of the aromatic characteristics of coal, polycyclic aromatic hydrocarbons (PAH) are found in coal conversion products. Some of these compounds are known to be carcinogenic in experimental animals and in humans.

Trace metals in coal may also be mobilized during gasification and thus are potential pollutants. Analyses by Attari (1973) of pilot plant operations indicated substantial losses of mercury, selenium, arsenic, tellurium, lead, and cadmium from solid residues. Other metals, such as antimony, vanadium, nickel, and beryllium, remained in the solid phase. The characteristics and transport of the metals mobilized during gasification and the mobility of those remaining in the solid phase are largely unknown. According to Jones et al. (1977), trace elements of primary concern in coal gasification are:

- antimony
- arsenic
- barium
- beryllium
- boron
- cadmium
- chlorine
- chromium
- copper
- fluorine
- lead
- mercury
- molybdenum
- nickel
- selenium
- sulfur
- tellurium
- uranium
- vanadium
- zinc.

MUNICIPAL

City of Gillette

Sewage Treatment Plant—

Sources at the Gillette Wastewater Treatment Plant include leakage from aeration, secondary clarifier and aerobic digester tanks, seepage from the sludge holding pond, and seepage from the oxidation pond. Sources related to the sludge holding pond are described elsewhere.

Leakage from the tanks may have about the same quality as incoming sewage, although the quality of basal sludge may be superimposed. No data are available on the quality of wastewater in the Gillette wastewater treatment plant. A first estimate based on information from Metcalf and Eddy (1975) on the typical composition of medium strength domestic sewage is included in Table 3-21.

Also included in Table 3-21 are possible values of chemical constituents in the "carrier" water. These values were given by Nelson et al. (1976) for the City of Gillette water supply. It is assumed that no changes in concentration occur during domestic uses. Also, possible effects of infiltration from the Donkey Creek line are neglected. The high COD, TOD, and BOD values indicate that organics constitute a potential contaminant in the shallow groundwater system. Similarly, total nitrogen is high.

Since the groundwater flow system is anaerobic, however, nitrate values should remain low. Another chemical constituent in the carrier water which is beyond recommended limits is sulfate.

TABLE 3-21. HYPOTHETICAL QUALITY OF WASTEWATER, GILLETTE TREATMENT PLANT (Nelson et al.,1976)

Constituent	Concentration (ppm)
Suspended solids - total	200
- fixed	50
- volatile	150
BOD (5-day)	200
TOC	200
COD	500
Nitrogen - total as N	40
- organic	15
- free ammonia	25
- nitrites	0
- nitrates	0
Phosphorus - total as P	10
- organic	3
- inorganic	7
Alkalinity - as $CaCO_3$	100
Grease	100
Potassium	9.5
Calcium	305
Magnesium	158
Sodium	220
Sulfate	920
Chloride	36
Bicarbonate	660
TDS	1,888

Sludge settled in the base of aeration, clarifier, and digester tanks may also contribute heavy metals to groundwater. Other constituents entering groundwater from the tanks include fecal bacteria and virus. Also present are amoeboid cysts, intestinal worm eggs, and parasitic fungi.

The "oxidation" pond appears to be an overloaded facultative system with operating characteristics of an anaerobic lagoon. Consequently, wastewater undergoes some anaerobic digestion. The quality of water in the pond may be a blend of incoming and outgoing wastewaters.

Wastewaters entering the "oxidation" pond from the aerobic digesters will reflect the quality of treatment in the activated sludge process. Such treatment is minimal in the Gillette Treatment Plant. Therefore, as a first approximation, the values for medium concentration sewage given in Table 3-21 are assumed also to be representative of wastewater entering the lagoon.

According to the Missouri Basin Engineering Health Council (1971), treatment effectiveness of a pond in Saskatchewan was as follows: suspended solids, 70 percent; BOD, 55 percent; COD, 60 percent; and grease, 75 percent. If Gillette's pond shows similar efficiencies and the corresponding values are used along with those values shown in Table 3-21, resultant effluent concentrations would be BOD, 90 ppm; COD, 200 ppm; and grease, 25 ppm. The high BOD and COD values reflect organics which should be considered a pollutant present in the pond. Chemical constituents increase in concentration because of evaporation. However, changes in sulfate concentrations will occur because of the formation of H_2S. Also, because of anaerobic condition, nitrogen constituents will remain about the same.

Digestion in anaerobic ponds leads to the formation of organic acids, lowering the pH. Similarly, the reducing conditions in anaerobic ponds also increase heavy metal mobility (Fuller, 1977). Lund et al. (1976) observed heavy metals in soil solution extracts 3 meters below the base of effluent ponds constructed in coarse-textured soils. Metal concentrations were lower than corresponding values found in extracts beneath sludge ponds, because sludges tend to accumulate heavy metals. Nevertheless, the possibility of contamination of groundwater beneath the lagoon at Gillette by heavy metals should be considered a real possibility. Analyses (courtesy of Ms. Paddock, Supervisor, water and wastewater plants, City of Gillette) of heavy metals in "treatment plant water" suggest that high zinc levels might be present in lagoon water (see section on "Sludges").

The lagoon at the Gillette Treatment Plant might contribute bacteria, viruses, and other pathogenic organisms to the shallow groundwater system.

It appears that the septic tank septage (material remaining in the tank and not discharged to leach fields) is disposed of mainly at the City of Gillette landfill. However, it is entirely possible that septage is occasionally discharged into the sewer system. In this case, shock concentrations may reach the treatment plant. Table 3-22 shows septage characteristics reported by Silberman (1977).

In addition to the constituents found in normal sewage (and septage), the

TABLE 3-22. SEPTIC TANK SEPTAGE CHARACTERISTICS AS REPORTED IN THE LITERATURE (all units in ppm, except pH) (Silberman, 1977)

Septage characteristics[a]	Minimum	Maximum
Total solids	6,380	130,000
Total fixed solids	1,880	59,100
Total volatile solids	4,500	71,400
Total suspended solids	5,200	93,400
Fixed suspended solids	1,600	9,000
Volatile suspended solids	3,600	30,100
Biochemical oxygen demand	3,780	12,400
Chemical oxygen demand	24,700	62,500
Ammonia nitrogen	40	150
Nitrite nitrogen	0.2	1.3
Nitrate nitrogen	0.87	9.0
Organic nitrogen	26	26
Total phosphorus	20	310
Orthophosphate	10	170
Chromium	1	1
Alkalinity	1,020	1,020
Iron	163	200
Manganese	5.0	5.4
Zinc	50	62
Cadmium	0.2	0.2
Nickel	1.0	1.0
Mercury	0.022	0.1
Hexane extractables	9,561	9,561
Copper	8.5	8.5
pH	4.2	9
Aluminum	50	-
TOC	15,000	-
Grease	9,600	-
Lead	2	-

[a] Minimum and maximum values are presented to show that septage characteristics vary substantially.

Gillette Treatment Plant receives industrial wastes of an unknown nature. These should be considered as potential pollutants. Table 3-22 lists hazardous wastes which are possibly discharged into the Gillette sewer system.

Sewage sludge—According to Todd et al. (1976), the ranking of pollutants associated with sewage sludge is:

- Physical — Minor
- Inorganic chemical — Primary
- Trace elements — Primary
- Organic chemical — Primary
- Bacteriological — Primary
- Radiological — Minor.

Sludge from the activated sludge process normally contains up to 99 pounds of water per pound of sludge solids (U.S. Environmental Protection Agency, 1974). Consequently digestion occurs under anaerobic conditions. The solid matter in sludge may consist of 70 percent organic and 30 percent inorganic substances (Health Education Service, nd). However, Sommers et al. (1976) reported 50 percent organic matter in sludge collected from eight Indiana cities.

A breakdown of the composition of raw and anaerobically digested sludge, reproduced from a report by Wyatt and White (1975), is given in Table 3-23. The high alkalinity and organic acid levels should be noted. Sommers et al. (1976) found that the predominant form of N in sludges was organic -N, and that NH_4-N constituted greater than 90 percent of the total inorganic N in sludges examined from eight Indiana cities. Ammonia concentration in wet sludges fell within the range 200 to 500 ppm in the same study. With drying of the sludge, therefore, one would expect production of considerable NO_3-N. This could be a source at the Gillette sludge disposal pond.

Organic matter in sludge has an affinity for the heavy metals in wastewater (Council for Agricultural Science and Technology, 1976). For example, Mitchell (1964) reported that copper, cobalt and chromium chelates were found in the fulvic acid fraction of organic matter. Concentrations of heavy metals vary widely from city to city, depending for example on degree of industrialization, storm water volumes, etc. Table 3-24 presents metals found in sludges (Dean and Smith, 1973). All metals are present in excessive concentrations; however, levels of lead, copper, and zinc are particularly high. Regarding mobility of heavy metals in sludge, studies by Lund et al. (1976) demonstrated that heavy metals migrated to depths as great as 3 meters below anaerobically digested sludge holding ponds. The metals examined were Zn, Cd, Cu, Cr, and Ni. The soils were coarse-textured. The authors found that redistribution of metals was closely related to changes in COD of soil samples with depth. Metal movement was thus attributed to the formation of organic chelates. Other possible factors promoting metal migration include pH and oxidation reduction potential. For example, during the first stage of anaerobic digestion of sludge, organic acid formation lowers the pH to a value of about 5.1 (Health Education Service, nd). The lower pH promotes the flux of cationic heavy metals (Fuller, 1977). Also, reducing conditions in soil promotes the movement of As, Be, Cr, Cu, Cn, Fe, and Zn, but has little effect on

TABLE 3-23. TYPICAL CHEMICAL COMPOSITION OF RAW AND ANAEROBICALLY DIGESTED SLUDGE (Wyatt and White, 1975)

	Raw primary sludge		Digested sludge	
Item	Range	Typical	Range	Typical
Total dry solids (TS), %	2.0-7.0	4.0	6.0-12.0	10.0
Volatile solids (% of TS)	60-80	65	30-60	40.0
Grease and fats (ether soluble, % of TS)	6.0-30.0	( )^a	5.0-20.0	( )^a
Protein (% of TS)	20-30	25	15-20	18
Nitrogen (N, % of TS)	1.5-4.0	2.5	1.6-6.0	3.0
Phosphorus (P_2O_5, % of TS)	0.8-2.8	1.6	1.5-4.0	2.5
Potash (K_2O, % of TS)	0-1.0	0.4	0.0-3.0	1.0
Cellulose (% of TS)	8.0-15.0	10.0	8.0-15.0	10.0
Iron (not as sulfide)	2.0-4.0	2.5	3.0-8.0	4.0
Silica (SiO_2, % of TS)	15.0-20.0	( )^a	10.0-20.0	( )^a
pH	5.0-8.0	6.0	6.5-7.5	7.0
Alkalinity (ppm as $CaCO_3$)	500-1,500	600	2,500-3,500	3,000
Organic acids (ppm as HAc)	200-2,000	500	100-600	200
Thermal content (Btu/lb)	6,800-10.000	7,600^b	2,700-6,800	4,000^c

[a] Data not shown in reference cited

[b] Based on 65 percent volatile matter

[c] Based on 40 percent volatile matter

the movement of Cd, Pb, and Hg (Fuller, 1977).

TABLE 3-24. METALS IN SLUDGE, 1971-1973
(Dean and Smith, 1973)

Element	Literature: Geometric mean (ppm)	Literature: Spread[a]	Atomic absorption geometric mean (ppm)
Cd	61	5.89	93
Cu	906	2.66	1840
Hg	14.5	5.24	3.2
Ni	223	4.54	733
Pb	404	4.13	2400
Zn	2420	2.78	6380

[a] Spread is antilog of standard deviation of log-normal distribution.

Anaerobic conditions obviously occur in both the sludge lagoon and "oxidation" pond at the Gillette wastewater treatment plant. Because of the shallow water table at the site, heavy metals may be introduced almost directly into the aquifer. A mitigating factor, however, is that the benthic deposits may have clogged the bottoms of both the sludge pond and "oxidation" pond.

Twenty samples of water at the Gillette wastewater treatment plant were analyzed in July 1976 for the following heavy metals: Pb, Zn, Cd, Cr, and Hg. According to the results (courtesy Ms. Paddock), values of Cd, Cr, and Hg were consistently below detection limits. One sample showed a lead concentration of 0.5 ppm and the remaining 19 were less than 0.1 ppm in lead. In contrast to these metals, the concentrations of Zn averaged 0.289 ppm. Undoubtedly, all metals are more highly concentrated in Gillette plant sludge, and the concentration of zinc may be excessively high.

In addition to chemical pollutants, sludge contains high concentrations of fecal coliform bacteria and viruses, and lesser quantities of intestinal and respiratory organisms (Dean and Smith, 1973). Also amoeboid cysts, intestinal worm eggs and parasitic fungi may be present (Dean and Smith, 1973). Such organisms remain viable in sludge.

Sewerline leakage—Sewer leaks allow raw sewage to enter the subsurface environment. The sewage comes from households and businesses in the community and, in the case of Gillette, industry as well. Seasonal variation of sewage composition can occur due to varying proportions of domestic and industrial waste. Gillette wastes have a higher domestic fraction during the summer because summer populations are higher than winter populations. Industry levels are relatively stable year round.

Dissolved minerals in Gillette sewage include all major constituents (Ca, Na, K, Mg, HCO_3, SO_4, Cl) and several trace constituents (principally Fe, Cu, Mn). Diluted organics include nitrogen forms such as ammonium, nitrate, urea, and proteins. Settleable solids include grit, sand, soaps, greases, tars, animal fats, hair, oil, and other organic matter. All of these species can be thought of as potential pollutants, although the mobility of the various substances will vary considerably.

Septic Tanks—

The characteristics of septic tanks as potential pollution sources were presented earlier under the discussion of mine sanitary wastes.

Landfills or Dumps—

The Gillette landfill site encompasses the following sources:

- Metal disposal area
- Oil waste disposal site
- Dead animal pit
- Garbage trenches
- Oily wastes and septic tank pumpage sites
- Tire disposal site
- Covered dump.

Metal disposal area—This area is used for disposal of metal objects, such as refrigerators, old cars, and barrels. Also tires, batteries, and wooden items are included. Potential pollutants associated with metal items (e.g., in alloys) could include any or all heavy metals, such as manganese, iron, aluminum, chromium, antimony, lead, copper, cadmium, nickel, and zinc. Since hazardous wastes of all types are permitted at the waste disposal site, the metal drums could contain residues ranging from oil to pesticides.

Oily waste disposal area—Waste oils in the disposal pit may include crankcase oil, transmission fluid, gear lubricants, hydraulic oils, and possibly kerosene and other solvents. Representative assays of crankcase drain oils indicate the presence of the following: carbon, nitrogen, sulfur, lead, zinc, barium, calcium, phosphorus, and iron. Additives included with the original lubricating oil, such as detergents and pour-depressants, may be present in crankcase oil. The organic fraction of additives may be dissipated by combustion or reactions with the oil, but inorganics concentrate. According to Weinstein (1974), drain oils contain significant amounts of unchanged polyisobutylene and polymethacrylate additives. The percent by weight of nitrogen in crankcase drain oils may range from 0.13 to 0.21 (Weinstein, 1974).

The solution resulting from flushing service station gasoline tanks may be dumped into the oil waste pit. Such waste could include high organic and lead concentrations. Because of the lack of restrictions at the landfill, it is possible that hazardous wastes could be disposed of in the oil waste pit. Table 3-22 lists possible hazardous wastes.

Open burning is permitted near the oil waste disposal site. Pesticide containers and other wastes are accepted. Burning of these items could create fly ash with high concentrations of organics and possibly heavy metals.

Dead animal pit—The dead animal pit is a source of high BOD, COD, and TOC, as well as lesser amounts of chemical constituents. The high TOC suggests that organics could migrate from the pit. Pathogenic organisms and virus are possibly present in abundance. Substances used in the euthanasia of the animals will also be present in unknown concentrations.

Garbage disposal site—Garbage is disposed of in two active trenches, each about 30 to 40 feet wide, 400 to 500 feet long, and 20 to 30 feet deep. A third trench of the same dimensions is used to provide backfill for the above trenches. Surface drainage runs into the pits.

The range in quality observed in municipal landfill leachate is shown in Table 3-8, reproduced from a paper by Pohland and Engelbrecht (1976). These authors point out that leachate is most objectionable from a pollution viewpoint when containing high concentrations of organic matter, high TDS, and low pH. As shown on Table 3-8, the following constituents are potential contaminants: organics, nitrate, calcium, chloride, sodium, potassium, sulfate, manganese, magnesium, iron, zinc, copper, cadmium, and lead. Decreasing pH increases the solubility of heavy metals present in the waste. Similarly, anaerobic conditions at the soil-landfill interface will promote the mobility of heavy metals indigenous to the soil. The population of microorganisms in leachate may be limited by the initially elevated temperatures together with other inactivating properties (Pohland and Engelbrecht, 1976). In other words, pathogenic organisms might not be of concern as polluting sources in leachate.

The problem of leachate production and associated potential contaminants is aggravated at the Gillette disposal site by surface runoff into the trenches. Not only does such runoff promote leachate formation, but also contaminants are introduced with the runoff water. For example, the overburden layers immediately above the coal seam exposed by the trench were observed to contain free sulfur and gypsum. A water sample of runoff was collected from a pool at the base of the third trench in June 1977, the day after a thunderstorm in the area. Table 3-25 shows the results of an analysis of the sample. The sample was not preserved (except by freezing); consequently, results for pH, CO_3, HCO_3, NH_4, and NO_3 are questionable. An equivalents per million (epm) balance shows that the ratio of cations to anions is 1.23. Sulfate values are questionable because of the method used (Hach Kit) and errors are introduced by dilution to bring results within the range of the instrument. However, the values illustrate that probably high concentrations of chloride, sulfate, sodium, and calcium are introduced into solid waste during runoff. If the pH is as low as the value shown, runoff water may also contain heavy metals and promote the mobility of heavy metals in leachate.

TABLE 3-25. ANALYSIS OF RUNOFF SAMPLE IN THIRD TRENCH AT THE CITY OF GILLETTE LANDFILL IN JUNE 1977 (ppm except for pH)

Water constituent		Water constituent	
pH	4.95	Na	338
EC	32.0	K	18
Cl	545	Ca	499
CO_3	0	Mg	226
HCO_3	78.1	NH_4	6.16
SO_4	1,500	NO_3	2.80

Oil waste and septic tank pumpage pits—Two pits at the Gillette disposal site are used to dispose of oil wastes and septic tank pumpage. Observation of the types of wastes disposed of in these pits suggests that hazardous wastes are also included.

The type of oily wastes and associated contaminants are probably the same as those disposed of in the oil waste disposal pit, and hazardous wastes are probably among those given in Table 3-22.

No information is available on the quality of the septage disposed of in the septic tank pumpage pit. The characteristics of septage are known to vary considerably, particularly in communities which do not regulate the collection and disposal of septage (U.S. Environmental Protection Agency, 1974). "In these cases, septage haulers will indiscriminately include septic tank contents along with raw wastewater collected from pit toilets, wastes from camping trailer pump-out stations, waste motor oil from service stations, cutting oil and other hard-to-treat or toxic wastes from small industries throughout the communities" (U.S. Environmental Protection Agency, 1974).

Table 3-22 indicates the possible large range in septage characteristics. The high TOC and COD values illustrate that organics are a possible contaminant. Other constituents of concern are: nitrogen, chromium, iron, manganese, zinc, cadmium, nickel, copper, and aluminum. Septage may also contain high concentrations of parasite microorganisms and viruses.

Tire disposal site—Up the hill from the oily waste and septage disposal pits is an area for disposal of tires. Oil wastes are also evident in this pit, with associated potential contaminants. Tires are basically nonbiodegradable. Fecal matter from rodents may constitute a pollution source as do the remains of dead rodents. Tires are also a potential fire hazard. Constituents in fly ash from burning tires may be potential sources of contamination. Possibly included are organics and heavy metals.

Covered dump—No information is available on the areal extent and composition of solid wastes in the covered dump at the landfill site. Using present practices as a guide, it is possible that any or all of the contaminants discussed above are present.

Water Treatment Facility—

The two potential pollutants related to the City of Gillette water treatment plant are precipitated solids from the lime softening process and concentrated wastewater. Precipitated solids comprise $CaCO_3$ and are disposed of in the landfill.

A sample of treatment plant wastewater was obtained from Stone Pile Creek, directly behind the plant, in June 1977. The sample was not preserved (except by freezing). The resultant analysis of major constituents and other characteristics of the water sample are shown in Table 3-26. The ratio of cations to anions is 0.84, indicating errors in analyses, principally sulfate, or the presence of undetermined constituents. On the basis of this analysis, however, it appears that sulfate is the principal contaminant.

TABLE 3-26. JUNE 1977 ANALYSIS OF WATER FROM STONE PILE CREEK BEHIND GILLETTE WATER TREATMENT PLANT (ppm except for pH)

Water constituent		Water constituent	
pH	8.5	SO_4	1,350
EC	1.70	Na	55
Cl	14	K	11
CO_3	3.0	Ca	134
HCO_3	109.8	Mg	165

Urban Runoff—

Sartor and Boyd (1977) reported on studies to determine the nature and concentrations of contaminants in urban runoff. Results were based on samples collected for a number of studies throughout the U.S. Among the more significant conclusions with respect to pollutants were the following:

- Runoff from street surfaces is generally highly contaminated. In fact, it is similar in many respects to sanitary sewage.
- The major constituents of street surface contaminants were consistently found to be inorganic, mineral-like matter, similar to common sand and silt.

- The quantity of contaminant material existing at a given test site was found to depend upon the length of time which had elapsed since the site was last cleaned, intentionally (by sweeping or flushing) or by rainfall.
- The quantity of contaminated material existing on street surfaces was found to vary widely depending upon a range of factors.

Quantity and characteristics of contaminants observed in urban runoff in the studies by Sartor and Boyd (1977) are shown in Table 3-27. Note particularly the high concentrations of total solids, coliforms, zinc, copper, lead, and chromium.

Urban runoff for Gillette will also contain high concentrations of ordinary salt used for clearing roads.

Other Municipalities

The only identified potential pollution sources at outlying municipalities are sewage treatment plants. The sewage effluents at these point sources will be similar to wastes generated at the City of Gillette treatment plant, and the reader is referenced to that section of the report. Total dissolved solids may be lower at outlying municipalities, due to the lower TDS of the water supply itself. However, the actual makeup of the sewage effluents depends on the design and operation of the particular package plant.

TABLE 3-27. QUANTITY AND CHARACTERISTICS OF CONTAMINANTS IN URBAN RUNOFF (Sartor and Boyd, 1977)

Measured constituents	Weight means for all samples (lb/curb mile)
Total solids	1400
Oxygen demand	
BOD_5	13.5
COD	95
Volatile solids	100
Algal nutrients	
Phosphates	1.1
Nitrates	0.094
Kjeldahl nitrogen	2.2
Bacteriological	
Total coliforms (org/curb mile)	99×10^9
Fecal coliforms (org/curb mile)	5.6×10^9
Heavy metals	
Zinc	0.65
Copper	0.20
Lead	0.57
Nickel	0.05
Mercury	0.073
Chromium	0.11
Pesticides	
p,p-DDD	67×10^{-6}
p,p-DDT	61×10^{-6}
Dieldrin	24×10^{-6}
Polychlorinated biphenyls	1100×10^{-6}

SECTION 4

GROUNDWATER USAGE

Campbell County receives an average of only 15 inches of precipitation per year, much of which is in the form of snow. Most of the streams are ephemeral, but even permanent rivers, such as the Belle Fourche, are used only for stock watering and a small amount of irrigation. The primary water supply for all uses is groundwater.

Groundwater usage can be divided into four broad categories: municipal, industrial, agricultural, and rural domestic. The only major municipality within the project area is the City of Gillette. The core city is supplied with water through a City distribution system, while trailer courts and subdivisions on the periphery have each developed its own water system. The town of Wright, located at Reno Junction, also has its own water supply system. Major industries which use groundwater include coal strip mining, electric power generation, experimental gasification, and secondary oil recovery. Agricultural water uses include stock watering and some irrigation.

MUNICIPAL USAGE

City of Gillette

The primary location of municipal water usage is the City of Gillette. Now supporting a population of 13,000, most of the City itself is supplied through a central distribution system. Pump station logs and City meter records show that in 1976 average daily usage was approximately 105 gallons per capita and that the maximum daily usage was about 240 gallons per capita (Nelson, et al. 1976). Roughly 3 million gallons of water per day flow through the water treatment plant, of which approximately 1.7 mgd enter the sewage treatment plant (Jeff Smith, City Engineer, personal communication, 1977).

The City water comes from a mixture of hard and soft water wells. There are currently 20 operational hard water wells, all except 2 of which are located in a single well field northwest of the City and north of the railroad, in Sections 21 and 22, T50N, R72W. The wells range from 182 to 355 feet in depth and draw water from the Wasatch Formation. When they were drilled in 1969, water levels ranged from 60 to 80 feet below ground surface, and individual well yields were generally from 50 to 100 gpm (Anderson and Kelly, 1977). In 1976, the hard water wells were found to be producing at 75 percent of their original capacity (Nelson et al., 1976), and in September 1977, water levels were found to range between 78 and 94 feet below ground surface.

The hard water well system is clearly inadequate to meet the needs of Gillette's growing population. Not only is the water table as a whole declining, but the cones of depression from neighboring wells are interfering with one another (Nelson et al., 1976). The wells are in poor repair, with broken flow meters and pressure gages and valves that have rusted shut. There is no monitoring of the well system at this time.

In 1976, a consulting firm (Nelson et al., 1976) was hired by the City of Gillette to study the water supply situation. At their urging, the City expanded its soft water well system during 1977. The City currently has 12 soft water wells, 7 of which have been drilled into the Fort Union Formation during the past year. The City is not yet using these new wells because of sand problems. The five original Fort Union wells range in depth from 930 to 1,215 feet and have a total pumping capacity of 310 gpm. In 1976, these wells were found to be operating at 100 percent capacity (Nelson et al., 1976).

In addition, the City has three wells drilled into the Fox Hills Formation. They range in depth from 3,479 to 8,505 feet and have a total rated capacity of 575 gpm for two of them and a rated capacity of 75 gpm for the third. Two of the wells (#1 and #2) have been plugged back and perforated in the Fort Union Formation.

The City of Gillette has recently turned its attention to the Madison Formation as a potential municipal water supply. Although the Madison limestone is found at about 11,000 feet below the ground surface in the Gillette area, it is considerably closer to the surface east of Gillette. In July 1977, Pacific Power and Light Company, the Joint Powers Board of Campbell County, and the City of Gillette jointly began drilling a test well in the Madison Formation 10 miles northwest of Keyhole Reservoir. The well was drilled to 2,625 feet, and water rose to within 400 feet of the surface. If production and quality are found to be suitable, the City of Gillette has the option of developing a well field on 40 acres around this site. The City would then construct a pipeline to Gillette, a distance of about 50 miles.

Subdivisions and Trailer Courts

Subdivisions and trailer courts are springing up around the periphery of Gillette. Rather than hooking up to the City distribution system, these new developments are drilling their own wells. As of November 1976, records from the State Engineer's Office showed that water rights permits had been granted to 26 subdivisions and trailer parks for a total of 4,650 acre-feet annually (afa).

RURAL DOMESTIC USAGE

Campbell County now has a rural population of about 2,000. Again, on the basis of a typical household usage of about 105 gallons per capita per day, usage is roughly 210,000 gallons per day (gpd).

The State Engineer has on file water rights permits for 238 domestic wells in the project area. Most of the wells range from 100 to 500 feet in depth, with three wells over 1,000 feet deep, and yields vary between 2 and 25 gpm.

INDUSTRIAL USAGE

Coal Strip Mining

The major use of water at the mines is for road dust suppression. Other uses include drinking, bathing, etc., and equipment wash water. All of the mines will be obtaining water both from pit discharge and from deep wells. Table 4-1 summarizes water requirements for dust suppression and cleaning/ domestic usage.

TABLE 4-1. MAJOR MINE SITE WATER USAGE

Mine	Dust suppression (gallons per day)	Source	Cleaning/domestic (gallons per day)	Source
AMAX Belle Ayr South	80,000 (summer)	pit discharge	2,500 - 4,000 (wash house only)	local wells
AMAX Eagle Butte	100,000	pit discharge	55,000	deep wells
ARCO Black Thunder	50,000 - 225,000	pit discharge and settling pond	60,000 - 100.000	4 wells
Carter North Rawhide	200,000 (summer)	mine drainage and sewage treated effluent	31,000	1 well
Kerr-McGee Jacobs Ranch	100,000	pit discharge	-	-
Sun Oil Cordero	350,000 (storage tank)	pit discharge and package treatment plant effluent	15,000 (domestic only)	wells 300 to 1,000 feet deep
Wyodak	60,000	pit discharge	10,000 (domestic only)	9 wells in Fort Union Formation

Water requirements for dust suppression vary seasonally with peak water usage during the summer months. In addition, extremely heavy traffic or wind conditions can increase water demands. Excess industrial water during the winter months will be pumped into holding tanks or mine settling ponds. The U.S. Geological Survey (1975) states that excess pit discharge from AMAX's Belle Ayr South mine will be diverted to Donkey Creek.

Water for cleaning and domestic purposes is being supplied by local groundwater wells. This includes water for plant wash, steam cleaning, and personal usage. AMAX estimates personal usage to be about 50 gpd per employee.

Steam Electric Power Generation

Although both the operating power plant and the one under construction are designed to be air-cooled, water losses occur in the following areas: boiler blowdown, demineralizer, evaporation from ash pond, sanitary wastes, equipment wash water, and floor and equipment drainage. Anticipated water requirements for the two power plants are 200 to 300 gpm. The current source of water is from wells in the Fort Union and Fox Hills Formations. When the new plant goes on line in June 1978, the major water supply will be treated sewage effluent from the Gillette sewage treatment plant (Black Hills Power and Light Co., 1973).

Coal Gasification

Lawrence Livermore Laboratories is currently conducting in situ coal gasification experiments at the Hoe Creek site south of Gillette. The first experiment, carried out in October 1976, produced 66,067 gallons of water from the dewatering wells beyond that actually used in the gasification process. In addition, half of that amount again was produced as steam. It is not known at this time how the excess water is disposed of (Lawrence Livermore Laboratory, 1977).

Secondary Oil Recovery

According to the U.S. Bureau of Land Management (1974), estimated groundwater used for secondary oil recovery, exclusive of oil produced water, in Campbell County was 8,500 acre-feet in 1973. Little change was expected for the future. In northeastern Campbell County, water is obtained mostly from Inyan Kara rocks and the Minnelusa Formation; while in southeastern and western Campbell County, most of the secondary recovery water comes from the Fort Union and Lance Formations and the Fox Hills sandstone.

AGRICULTURAL USAGE

Agricultural water usage consists primarily of stock watering, with minor irrigation. As of November 1976, water rights permits were on file with the State Engineer for 439 stock wells in the project area. These range in depth from 1 to 640 feet, with the majority between 10 and 200 feet. The yields are mostly under 10 gpm, but range from 2 to 100 gpm. There are also 129 combined stock and domestic wells, 5 stock and irrigation wells, and 12 wells combining stock watering with commercial or industrial uses. In the last case, water is sold for construction, oil exploration, or other purposes.

The Wyoming Water Planning Program (1973) stated that in Campbell County consumptive water use can be assumed to be approximately 15 gpd for cattle and 3 gpd for sheep. The Wyoming Department of Agriculture (personal communication) reported that as of January 1976, there were 85,000 cattle and calves and 84,000 sheep in Campbell County. Using these figures, total water consumption for stock watering in Campbell County is approximately 1.5 mgd. Roughly 60 percent of this total is provided by groundwater. Therefore, a rough estimate of groundwater used for stock watering in Campbell County is 0.9 mgd.

Records from the State Engineer's Office (November 1976) show nine irrigation wells in the project area. Most of these are used by schools, cemeteries, etc., and have yields ranging from 30 to 100 gpm. Two of the wells are agricultural and have yields of 600 and 350 gpm. There are also five wells used for both irrigation and stock watering. These have yields ranging from 20 to 200 gpm.

SECTION 5

HYDROGEOLOGIC FRAMEWORK

This section is intended to provide the source-specific background information for the hydrogeologic framework upon which the various potential pollution sources identified in Section 2 are to be superimposed. Data and information gaps exist for many individual sources. These gaps will need to be filled before a complete assessment of the potential impact of these sources on groundwater quality can be made.

The section has been arranged according to five major interest areas — surface water hydrology, soils, geology, existing hydrogeology, and the modified hydrogeologic practices of the coal strip mining firms. The order of these areas of interest is of significance because, as the potential pollutants enter the system, they are usually subject to the influence of at least one of these interest areas.

SURFACE WATER HYDROLOGY

This discussion covers the surface hydrology and its relation to groundwater in the study area at present. Conditions during and after mining will also be discussed in the general framework. A detailed site-specific treatment of surface hydrology cannot be made until the mines provide complete access to their hydrologic data.

Precipitation and Evapotranspiration

The Powder River Basin is semiarid. Average annual rainfall is 15 inches; average potential evapotranspiration is 25 to 30 inches. Rainfall varies widely from year to year and is distributed unevenly during the year. Most rain comes from thunderstorms in the spring and early summer. Thunderstorm rainfall is very localized, intense, and of short duration.

Little naturally occurring surface water is found in the basin. Most rain received in the basin is carried back to the atmosphere by evapotranspiration. Only a small portion runs off as streamflow, or moves deep into the subsurface to recharge aquifers. Some small, shallow intermittent lakes can be found after rainfall. Only the Belle Fourche River and two of its tributaries, Donkey and Caballo Creeks, flow for extended periods of time during the year.

Watershed and Stream Morphology

The topography of the eastern Powder River Basin is gently rolling. Surface relief varies from east to west, particularly east of the coal burn line that marks the boundary between the Wasatch and Fort Union Formations. Elevations in the basin range from 4,500 to 5,000 feet.

Figure 5-1 shows the area selected for the monitoring study and the major watersheds intersected by the monitoring area. The monitoring area was arbitrarily divided into five watersheds: Rawhide Creek, which flows to the Powder River; the Belle Fourche River and two of its tributaries, Caballo and Donkey Creeks; and Little Thunder Creek, which flows to the Cheyenne River.

Drainage net structure appears to be dendritic. The basin has two regional joint sets trending northwest and northeast and, in some areas, drainage net development appears to slightly favor these directions. Major stream gradients are gentle. As an example, the Belle Fourche River has a gradient of 8 feet per mile just west of the Sun Oil Cordero lease.

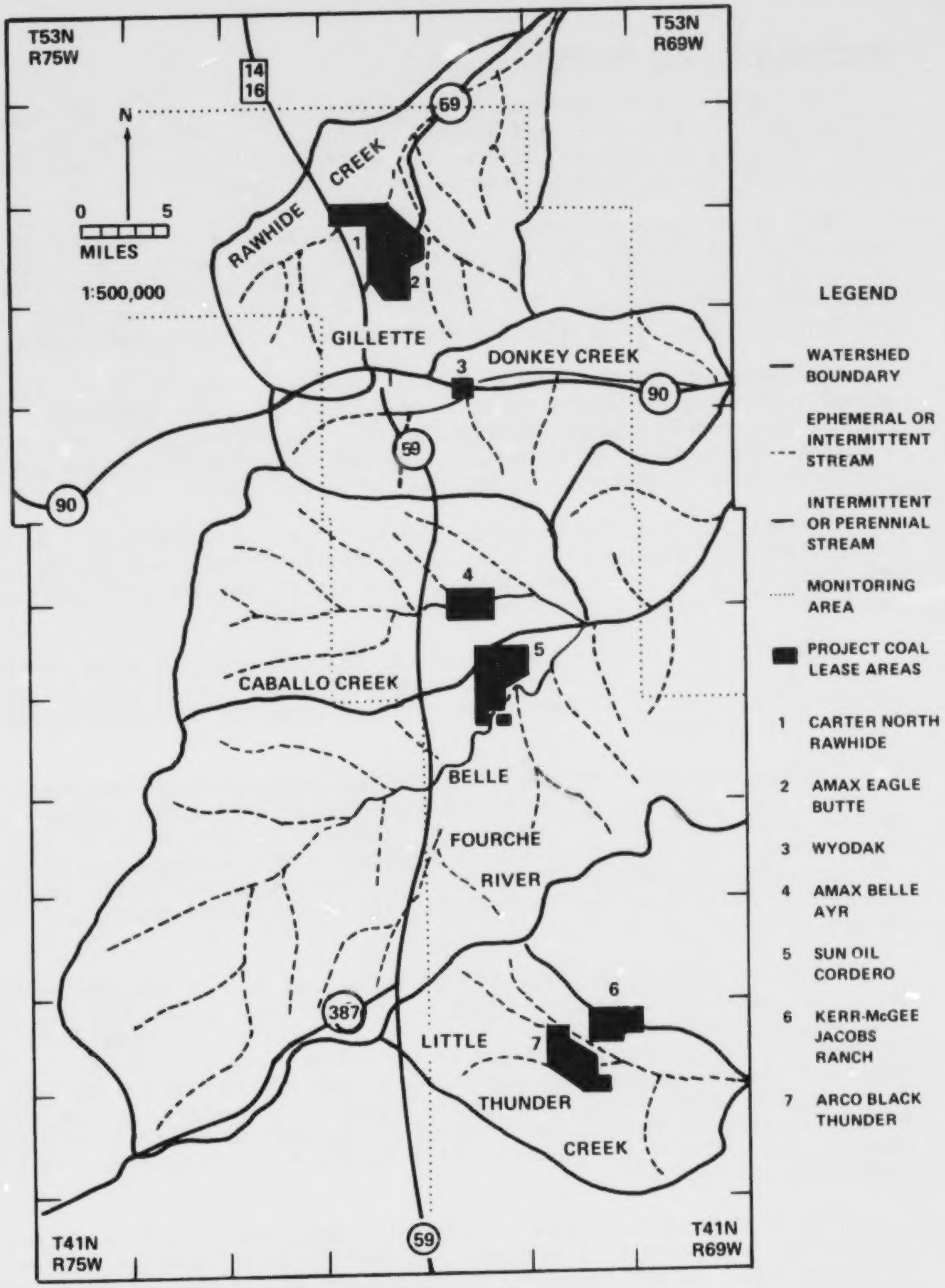
Streams generally occupy grassy swales or narrow floodplains. Meandering is very well developed on all but the smallest streams and meander scars are conspicuous in aerial photographs. Dry stream beds are grass covered and appear to contain little moveable coarse material.

Intermittent lakes that mark areas of internal drainage occur on all watersheds. Numerous stock water impoundments (stock tanks) are also constructed along smaller streams. Several stream reaches contain sequences of closely spaced tanks.

The northern third of Campbell County is a deeply dissected upland, with a similar but less severely eroded continuation of this upland occupying the western side of the County (number 4 in Figure 5-2). The relief of this dissected area is rolling to steep and broken, with numerous butte-like hills of scoria characterizing this upland. The entire area of this physiographic division is drained by the Powder River, the Little Powder River, and their tributaries.

South and east of the deeply dissected upland is a rolling divide (number 1 in Figure 5-2), the crest of which parallels the north-south Highway 59. This area in the central and southern parts, as well as the Rochelle Hills (number 2 in Figure 5-2), which border the eastern edge of this rolling divide, are drained by the Belle Fourche River and tributaries of the South Fork Cheyenne River. The predominantly gently sloping plains and tablelands of this rolling divide have local relief of 200 feet to 400 feet, with remnants of the old Missouri Plateau rising sharply from 100 to more than 1,000 feet about the divide.

East of the rolling divide is a broad, rough, broken, and in places, badlandlike escarpment that is locally called the Rochelle Hills (number 2 in Figure 5-2). It was formed by the burning of Wyodak coal in the outcrop, which protected the underlying Fort Union strata, thus forming this striking and prominent flat-topped ridge (U.S. Geological Survey, 1974a).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R75W
T53N
R69W
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16
59
N
0
5
MILES
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RAWHIDE
CREEK
1
2
GILLETTE
3
DONKEY CREEK
90
59
90
4
5
CABALLO CREEK
BELLE
FOURCHE
RIVER
387
6
7
LITTLE
THUNDER
CREEK
59
T41N
R75W
T41N
R69W
LEGEND
WATERSHED BOUNDARY
EPHEMERAL OR INTERMITTENT STREAM
INTERMITTENT OR PERENNIAL STREAM
MONITORING AREA
PROJECT COAL LEASE AREAS
1 CARTER NORTH RAWHIDE
2 AMAX EAGLE BUTTE
3 WYODAK
4 AMAX BELLE AYR
5 SUN OIL CORDERO
6 KERR-McGEE JACOBS RANCH
7 ARCO BLACK THUNDER

Figure 5-1. Watershed map.

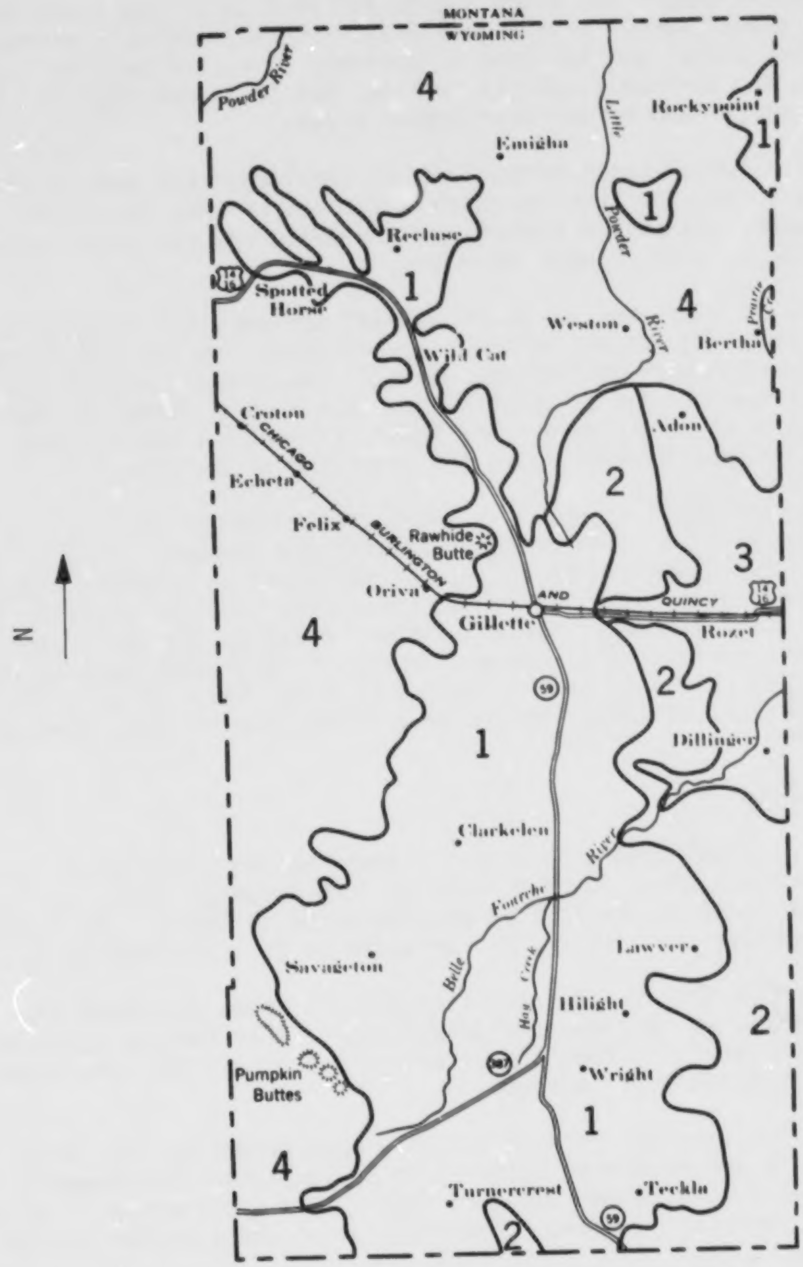

MONTANA
WYOMING
Powder River
4
Rockypoint
1
Emigh
Little Powder River
1
Recluse
14
Spotted Horse
1
Weston
4
Bertha
Prairie Cr.
Wild Cat
Croton
CHICAGO
Adon
Echeta
2
Felix
BURLINGTON
Rawhide Butte
3
Oriva
AND
QUINCY
14
N
4
Gillette
Rozet
59
2
Dillinger
1
Clarkelen
River
Fourche
Belle
Hay Creek
Lawver
Savageton
Hilight
2
387
Pumpkin Buttes
Wright
1
4
Turnercrest
Teckla
59
2

Figure 5-2. Physiographic divisions and drainage of Campbell County, Wyo.: (1) rolling divide; (2) Rochelle Hills escarpment; (3) eastward sloping plain; (4) deeply dissected upland (Soil Conservation Service, 1939).

The Rochelle escarpment drops 300 to 400 feet to a relatively low eastward sloping plane (number 3 in Figure 5-2). Streams are well entrenched throughout this plain, but the land is severely dissected only in local areas. On the whole, the surface is gently rolling, but it is modified in places by steep valley slopes and a few rough broken areas.

Areas of alluvial lands border most of the larger and many of the smaller drainage ways in the four physiographic divisions already described. Areas along the Powder, the Little Powder, and the Belle Fourche Rivers attain a width exceeding 3 miles in some locations.

The alluvial lands include both alluvial terraces and floodplains. Terraces occupy about 70 percent of the alluvial lands, having been formed before streams became so deeply entrenched. Some of the higher terraces are gently sloping and partly covered by alluvial fans built up by deposits from small drains issuing from the uplands. The lower terraces are nearly level; few of them are more than 30 feet above the adjoining floodplains.

These varying physiographic divisions within Campbell County produce varying soil properties of which the following are commonly found to be relief related: (1) depth of the solum; (2) thickness and organic matter content of the A horizon; (3) relative moisture content of the profile; (4) color of the profile; (5) degree of horizon differentiation; (6) soil reaction; (7) soluble salt content; (8) kind and degree of "pan" development; (9) temperature; and (10) character of the initial material (Buol et al., 1973). Undoubtedly, several of these factors have contributed to soil development in Campbell County.

Intermittent Lakes

Areas of internal drainage to small closed basins occur in all watersheds in the project area. During heavy or long duration rains, surface runoff collects in these basins to form shallow ponds or lakes. The lakes are intermittent because they quickly dry as water is lost by evaporation.

The areal distribution of intermittent lakes shows a pattern that follows the occurrence of shallow, strippable coal. They tend to occur where the Wasatch beds overlying the Fort Union coals are thin and they show a trend that follows the coal "outcrop."

These small closed basins have probably been formed by subsidence. The mechanism causing subsidence is believed to be compaction (diagenesis) of the thick coal seams during recent geologic time. This explanation is supported by the obvious correlation between the location of these basins and the thick, shallow coal beds.

Because these basins do not drain, salts brought in by runoff concentrate at the surface and in the soil. Soil maps show many of these basins contain a highly alkaline and sodic acid called McKenzie clay. These soils may contribute to the deterioration of groundwater quality when disturbed by mining.

Recharge from intermittent lakes is probably insignificant. The soils in the lake basins have a clay content and are often sodic, which probably has the effect of sealing the basin floors when water ponds on these soils.

Streamflow Characteristics

Streams may be classed as ephemeral, intermittent, or perennial. Ephemeral streams are dry except for very brief periods when they flow in response to heavy rainfall, which is usually caused by intense, short-duration thunderstorms. Intermittent streams flow for extended periods during the year but are dry for some period, usually during the summer when evapotranspiration rates are high and there is little or no rain. Perennial streams flow throughout the year.

Virtually all streams in the area are ephemeral or intermittent. Perennial flow occurs only during wet years in the lower reaches of the Belle Fourche River, the largest stream in the project area. Figure 5-3 shows a flow-duration curve for the Belle Fourche at Moorcroft, just east of the project area. This curve shows, for example, that discharge is greater than 0.5 cubic feet per second (ft^3/s) only 40 percent of the time.

Streamflow is variable and unpredictable. Mean values of discharge and peak flow return periods are obtained from sparse data and are almost useless for prediction. The best and most up-to-date work on streamflow characteristics is by Lowham (1976), who is the source for Figures 5-4 and 5-5. The figures show discharge-drainage area relations for streams in two hydrologic regions that occur in the monitoring area. These regions are shown in Figure 5-6.

Lowham's (1976) graphs give mean annual discharge (Qa) and peak discharge for various return periods (P100 = peak with 100-year return period). He states that these graphs are not applicable where stream characteristics have been altered by man and a few data discussed next suggest that streamflows in the monitoring area have been greatly altered by stock watering tanks.

By storing water the tanks reduce runoff volumes. At AMAX Eagle Butte, discharge in the Little Rawhide Creek where it enters and leaves the lease was 110 and 85 acre-feet respectively for the period March 1974 to June 1975 (U.S. Geological Survey, 1976). Note that flow volume decreased in the downstream direction. Based on drainage areas at these two points, Lowham's graphs for Region 3 (Figure 5-5) give mean annual flow volumes of 1,800 and 2,200 acre-feet. Aerial photos of the Little Rawhide Creek watershed upstream of the lease show at least 31 stock tanks in the 22-square-mile drainage area, and their presence may explain the very large difference between the estimated and observed flow volumes.

Stock tanks are found in great numbers throughout the monitoring area. Streamflow records at other mine sites also show flow volumes that are much lower than Lowham's estimates. Lowham's graphs give a mean discharge of 8 ft^3/s for the Belle Fourche at Sun Oil Cordero, but the Cordero Mining Co. (1976) reports that the river is dry for long periods and normally flows at less than 5 ft^3/s.

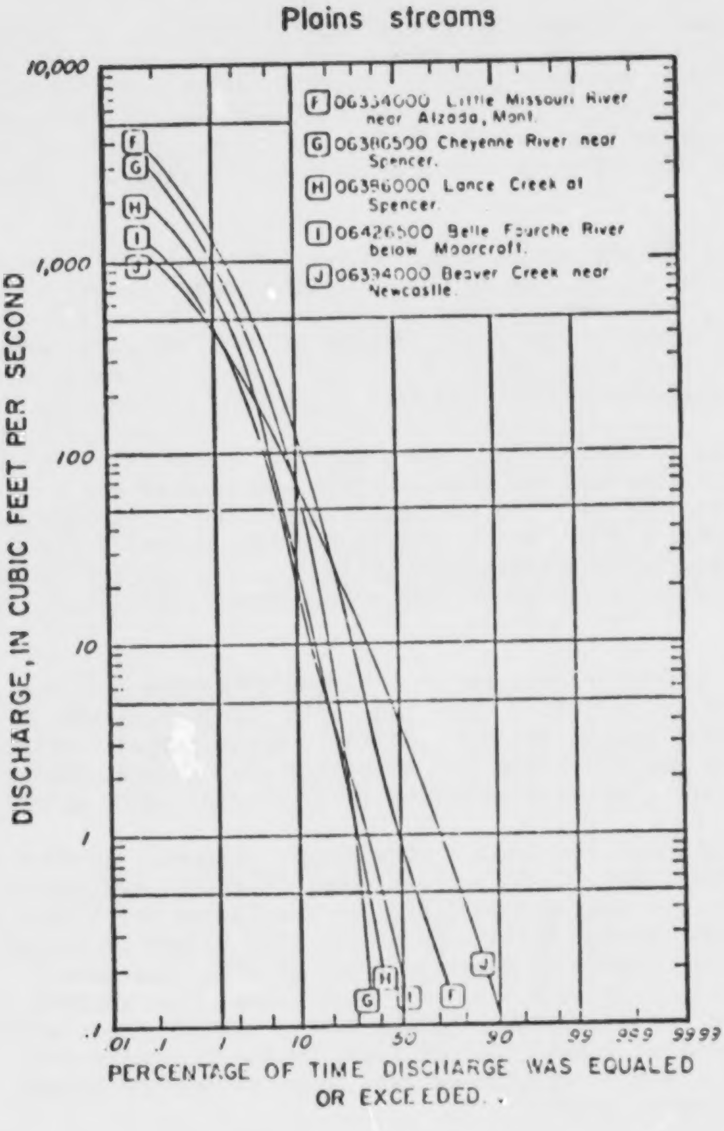


Figure 5-3. Flow duration curves for selected Wyoming streams (U.S. Bureau of Land Management, 1974).

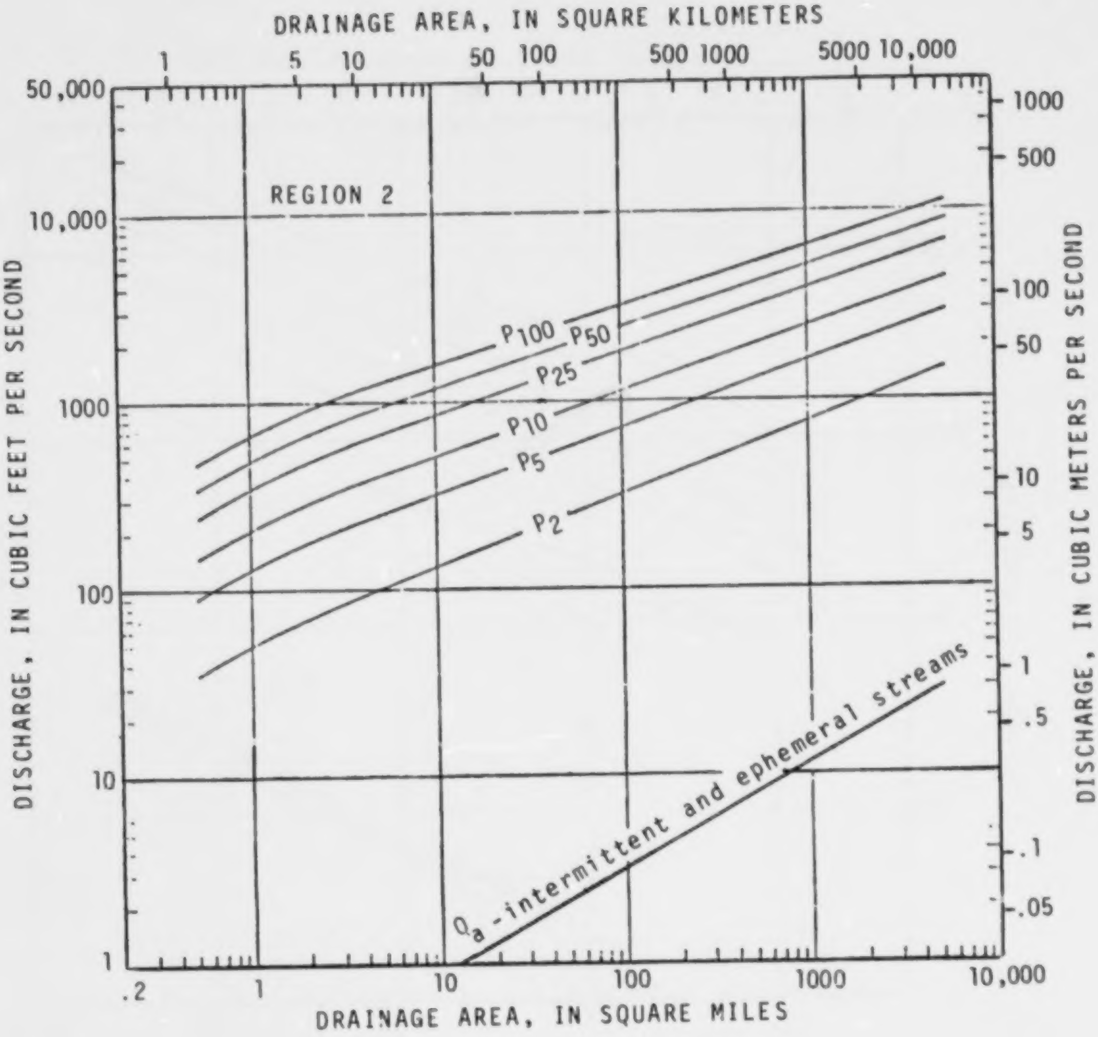


Figure 5-4. Relations for estimating flow characteristics in region 2 by using drainage area (from Lowham, 1976).

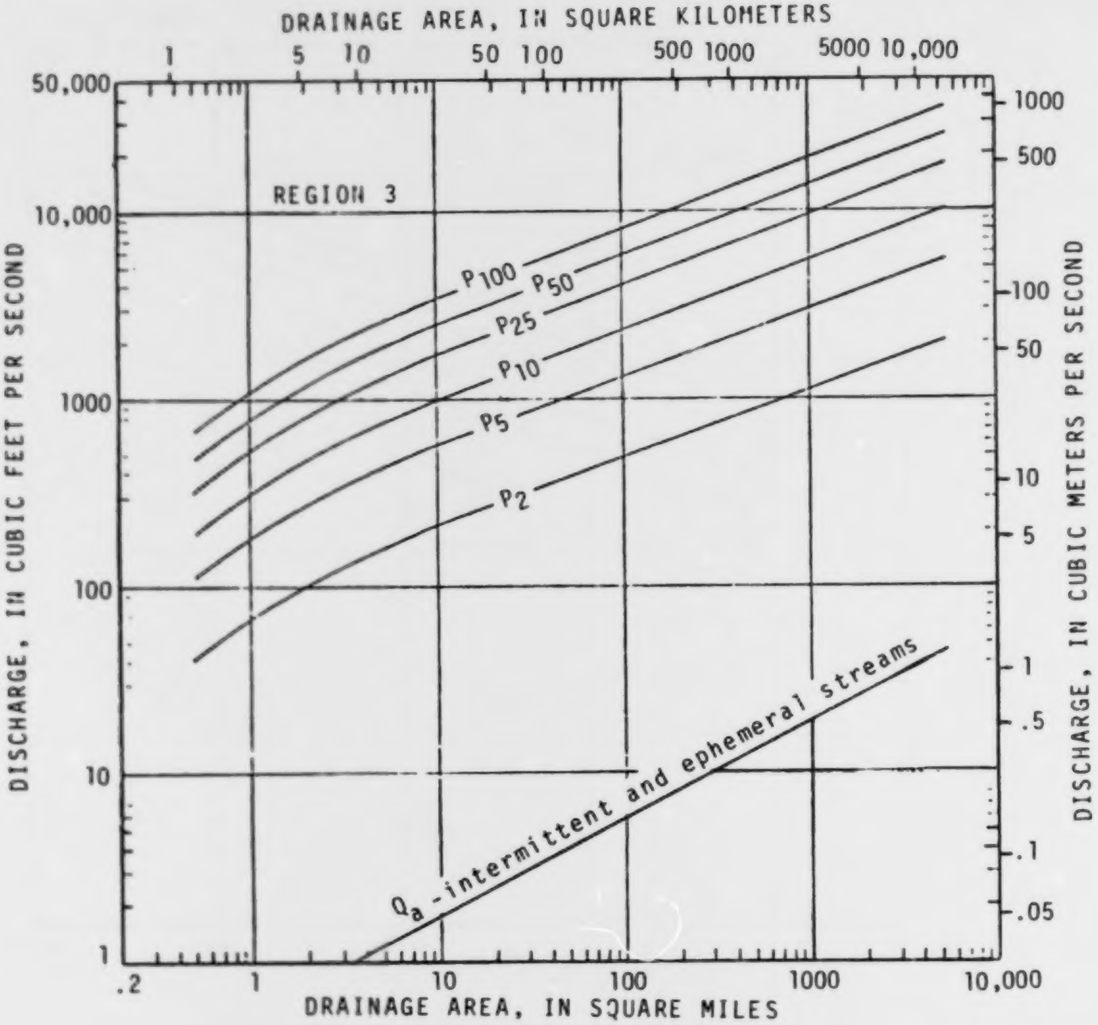


Figure 5-5. Relations for estimating flow characteristics in region 3 by using drainage area (from Lowham, 1976).

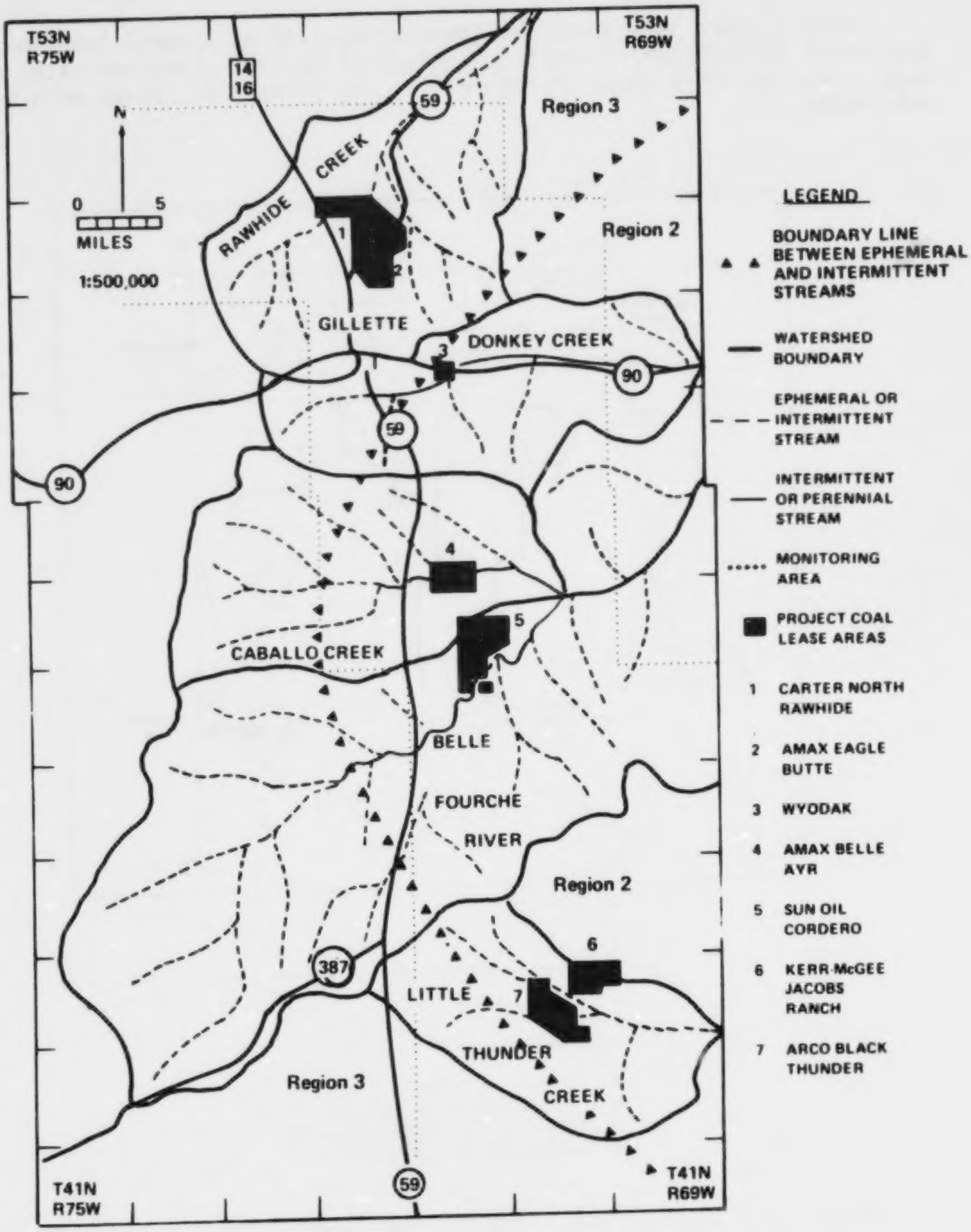
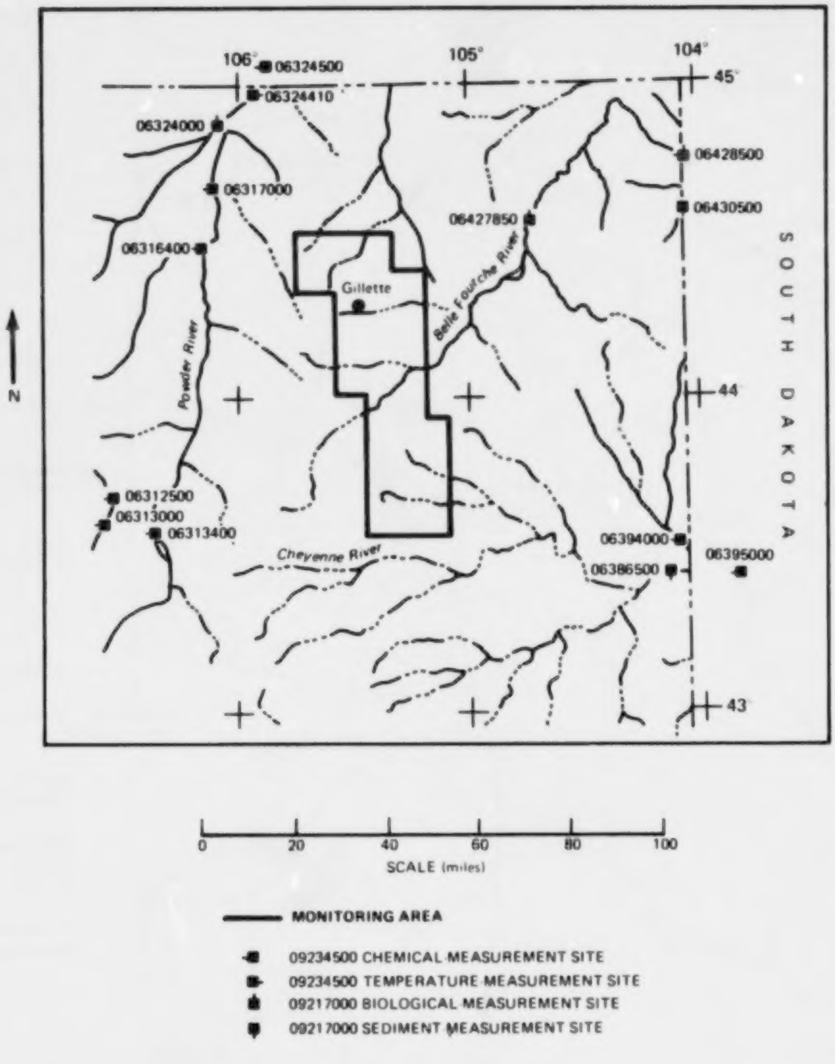

T53N
R75W
T53N
R69W
14
16
59
N
0
5
MILES
1:500,000
Region 3
Region 2
RAWHIDE CREEK
1
2
GILLETTE
3
DONKEY CREEK
90
59
90
4
5
CABALLO CREEK
BELLE
FOURCHE
RIVER
Region 2
387
6
7
LITTLE
THUNDER
CREEK
Region 3
59
T41N
R75W
T41N
R69W
LEGEND
BOUNDARY LINE BETWEEN EPHEMERAL AND INTERMITTENT STREAMS
WATERSHED BOUNDARY
EPHEMERAL OR INTERMITTENT STREAM
INTERMITTENT OR PERENNIAL STREAM
MONITORING AREA
PROJECT COAL LEASE AREAS
1 CARTER NORTH RAWHIDE
2 AMAX EAGLE BUTTE
3 WYODAK
4 AMAX BELLE AYR
5 SUN OIL CORDERO
6 KERR-McGEE JACOBS RANCH
7 ARCO BLACK THUNDER

Figure 5-6. Hydrologic regions at monitoring area.

Surface Water Quality

Surface water is sampled for chemical quality at several locations in the Powder River Basin by the U.S. Geological Survey. Sampling sites and type of analysis are shown in Figure 5-7. No sites are located within the monitoring area.



106°
105°
104°
45°
44
43
06324500
06324410
06324000
06317000
06316400
06428500
06430500
06427850
06312500
06313000
06313400
06394000
06386500
06395000
Gillette
Belle Fourche River
Powder River
Cheyenne River
SOUTH DAKOTA
N
0
20
40
60
80
100
SCALE (miles)
MONITORING AREA
09234500 CHEMICAL MEASUREMENT SITE
09234500 TEMPERATURE MEASUREMENT SITE
09217000 BIOLOGICAL MEASUREMENT SITE
09217000 SEDIMENT MEASUREMENT SITE

Figure 5-7. Surface water quality measurement sites (adapted from Water Resources Data for Wyoming, Part 2. Water Quality Records, U.S. Geological Survey, 1974a).

To show the range of constituents included in a chemical analysis, results from station 06428500 on the Belle Fourche River for 1974 are shown in Table 5-1. During this year, dissolved solids concentration ranged from about 750 to 2,000 ppm. The major dissolved constituent was sulfate, which ranged from 450 to 1,300 ppm. Calcium and bicarbonate were next in abundance. Their concentrations, which tended to be about equal, ranged from 100 to 400 ppm.

Surface water quality is also reported for streams on several mine lease sites in environmental impact studies where quality data have been collected as part of a program to gather baseline information. Their analysis generally shows sulfate as the major dissolved solids constituent followed by calcium, bicarbonate and, in some cases, sodium.

Surface Water—Groundwater Relationships

Strip mining of coal may have a great impact on shallow groundwater systems. The occurrence and movement of groundwater in these systems is directly related to the surface hydrology. This is the case both under natural conditions which prevail at the present and under modified conditions that will occur during and after stripping of the coal.

A general picture of the relationship between surface water and groundwater is provided by the streamflow characteristics of the project area. Ephemeral streams lose water to the streambed and are sources of recharge to groundwater. Intermittent streams lose water at certain times and receive groundwater at others. They are alternatively sources of recharge and points of groundwater discharge. Discharge of groundwater to intermittent streams is often not sufficient to cause flow but may provide enough water to sustain ponds in the streambed. Perennial streams are points of groundwater discharge at all times.

Streams in the project area generally grade from ephemeral to perennial with increasing watershed size. Higher elevations on the watershed are areas of recharge, both in ephemeral streams and in interstream areas. Recharge along stream channels is probably enhanced by seepage from stock tanks. Seepage takes place both through the tank bottom and often through the face of the dam, which causes water to pond in the channel for some distance downstream from the dam face.

At lower elevations on larger watersheds, groundwater may discharge to streams and sustain intermittent or perennial flow. Perennial flow appears only on large watersheds. The largest watershed in the project area, the Belle Fourche River, has intermittent flow at the Sun Oil Cordero lease where the drainage area is about 500 square miles.

Relative quantitives of runoff and recharge under premining conditions in the basin are poorly defined. Lowham's (1976) drainage area-discharge relations for Region 3 (Figure 5-5) give mean annual runoff values for 10- and 100-square-mile areas at 1.6 and 5.5 ft^3/s or 2.1 and 0.7 inches. As indicated earlier, these values are likely to be high. Smith (1974) estimates average annual headwater runoff to be 0.3 inch. Runoff at the AMAX

TABLE 5-1. REPRESENTATIVE CHEMICAL MEASUREMENTS FOR SURFACE WATER QUALITY (U.S. Geological Survey, 1974a)

CHEYENNE RIVER BASIN

06428500 BELLE FOURCHE RIVER AT WYOMING-SOUTH DAKOTA STATE LINE

LOCATION. Lat 44°44'59", in NE¼NW¼NW¼ sec. 18, T.9 N., R.1 E., Butte County, S. Dak., at county bridge, 4.0 mi northwest of Belle Fourche, S. Dak., and 8.0 mi downstream from gaging station.

DRAINAGE AREA. 3,280 mi^2, approximately (at gaging station).

PERIOD OF RECORD. Chemical analyses: October 1965 to September 1974. Water temperatures: October 1965 to September 1974.

EXTREMES: 1973-1974:
Specific Conductance – Maximum daily observed, 2,620 micromhos Jan. 14; minimum daily, 726 micromhos Mar. 6.
Water Temperatures – Maximum, 31.0°C June 19; minimum, freezing point on many days during November to March.
Period of Record:
Specific Conductance – Maximum daily, 2,840 micromhos Jan 17, 1970; minimum daily, 461 micromhos Apr. 12, 1971.
Water Temperatures – Maximum, 31.0°C June 19, 1974; minimum freezing point on many days during winter period.

CHEMICAL ANALYSES, WATER YEAR OCTOBER 1973 TO SEPTEMBER 1974

Date	Time	Instantaneous discharge (cfs)	Dissolved silica (SiO_2) (mg/l)	Dissolved Calcium (Ca) (mg/l)	Dissolved Magnesium (Mg) (mg/l)	Dissolved sodium (Na) (mg/l)	Dissolved Potassium (K) (mg/l)	Bicarbonate (HCO_3) (mg/l)	Carbonate (CO_3) (mg/l)	Dissolved sulfate (SO_4) (mg/l)	Dissolved chloride (Cl) (mg/l)	Dissolved fluoride (F) (mg/l)
Oct. 24...	0800	34	7.0	230	75	92	7.7	174	0	910	4.6	0.7
Nov. 15...	0800	53	9.8	220	66	70	6.7	203	0	790	5.5	0.7
Dec. 06...	1410	35[a]	11	260	93	96	7.4	235	0	1000	7.6	0.7
Jan. 10...	1700	8.0[a]	13	370	110	140	9.5	378	0	1300	9.2	0.8
Feb. 14...	1710	80[a]	11	250	38	79	7.7	215	0	770	5.3	0.6
Mar. 14...	1315	122	8.6	170	47	50	8.6	185	0	570	6.1	0.5
Apr. 25...	1715	229	10	130	38	50	6.7	170	0	440	3.8	0.6
May 08...	1815	106	15	190	57	68	6.3	207	0	660	3.8	0.6
June 06...	1000	67	8.0	215	74	100	8.6	183	0	900	3.6	0.7
July 04...	0900	133	6.3	130	29	100	6.7	122	0	550	5.4	0.7
Aug. 08...	1415	106	5.3	99	34	98	7.4	189	0	430	7.3	0.6
Sep. 12...	0900	33	4.5	170	63	110	8.4	210	0	740	7.3	0.7

[a] Daily mean discharge.

(continued)

TABLE 5-1 (continued)

CHEYENNE RIVER BASIN
06428500 BELLE FOURCHE RIVER AT WYOMING-SOUTH DAKOTA STATE LINE

Date	Dissolved nitrate (N) (mg/l)	Total phosphorus (P) (mg/l)	Dissolved solids (sum of constituents) (mg/l)	Dissolved solids (tons/ acre-ft)	Dissolved solids (tons/ day)	Hardness (Ca,Mg) (mg/l)	Non-carbonate hardness (mg/l)	Sodium adsorption ratio	pH (units)	Specific conductance (micromhos)	Temperature (°C)
Oct. 24...	0.05	---	1410	1.92	129	890	750	1.3	8.2	1750	10.5
Nov. 15...	0.11	0.02	1270	1.73	182	830	660	1.1	8.2	1610	1.0
Dec. 06...	0.05	0.01	1610	2.19	152	1000	810	1.3	8.1	1940	0.5
Jan. 10...	0.11	0.02	2160	2.94	46.7	1400	1100	1.6	7.9	2470	0.0
Feb. 14...	0.18	0.04	1260	1.71	272	780	600	1.2	8.0	1570	0.0
Mar. 14...	0.36	0.01	956	1.30	315	630	480	0.9	7.9	1260	6.0
Apr. 25...	0.18	0.02	760	1.03	470	480	340	1.0	8.0	1020	16.0
May 08...	0.07	0.01	1100	1.50	315	710	540	1.1	8.3	1300	17.0
June 06...	0.05	0.01	1400	1.90	253	840	690	1.5	8.2	1730	15.5
July 04...	0.38	0.02	890	1.21	320	440	340	2.1	7.7	1220	17.5
Aug. 08...	0.07	0.01	775	1.05	222	380	230	2.2	8.2	1100	23.5
Sep. 12...	0.00	0.00	1200	1.63	107	680	510	1.8	8.2	1510	10.0

FIELD DETERMINATIONS

Date	Time	Instantaneous discharge (cfs)	Turbidity (JTU)	Dissolved oxygen (mg/l)	Fecal coliform (col./100 ml)
Oct. 24...	0800	34	9	9.5	110
Jan. 10...	1700	8.0[a]	3	9.5	10[b]
Apr. 25...	1715	229	170	7.5	145
July 04...	0900	133	90	7.2	2700

[a] Daily mean discharge.

[b] Non-ideal counting conditions

(continued)

TABLE 5-1 (continued)

CHEYENNE RIVER BASIN
06428500 BELLE FOURCHE RIVER AT WYOMING-SOUTH DAKOTA STATE LINE

SPECIFIC CONDUCTANCE (micromhos/cm AT 25°C), WATER YEAR OCTOBER 1973 TO SEPTEMBER 1974

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	1690	1650	1900	2050	1280	1320	1700	1260	1880	1450	1130	1350
2	1670	1630	1840	2150	1370	1500	1730	1330	1740	1840	1120	1340
3	1650	1610	1760	2210	1360	1590	1700	1370	1640	1690	1120	1350
4	1670	1590	1950	2230	1330	1600	1730	1440	1620	1120	1110	1330
5	1700	1680	1850	2260	1410	1140	1720	1430	1540	1120	1100	1350
6	1740	1630	1790	2320	1460	726	1680	1440	1740	1090	1000	1370
7	1780	1700	1990	2360	1530	870	1620	1450	1740	1120	975	1380
8	1800	1710	1890	2310	1600	847	1720	1450	1760	1100	956	1420
9	1700	1630	1980	2480	1640	872	1700	1510	1860	1110	1020	1470
10	1640	1680	1780	2500	1680	983	1700	1470	1840	1110	1010	1520
11	1570	1680	1730	2520	1580	1120	1660	1510	1820	1120	985	1570
12	1460	1740	1940	2600	1660	1190	1550	1550	1830	1140	1070	1590
13	1640	1620	1910	2590	1600	1240	1600	1450	1800	1130	1060	1620
14	1680	1630	1890	2620	1550	1260	1700	1570	1780	1130	1060	1660
15	1710	1590	1920	1560	1590	1380	1730	1620	1820	1130	1040	1660
16	1700	1700	1940	1180	1490	1400	1720	1640	1870	1130	1070	1710
17	1740	1700	1950	1200	1470	1420	1700	1650	1940	1120	1090	1780
18	1730	1680	1960	1200	1500	1470	1620	1730	1940	1120	1140	1820
19	1720	1680	1970	1410	1480	1520	1620	1680	1840	1020	1150	1870
20	1720	1760	1980	993	1440	1600	1450	1660	1880	980	1190	1900
21	1720	1820	1980	1110	1390	1680	1380	1670	1670	920	1240	1950
22	1750	1900	1840	1060	1100	1670	1510	1660	1820	760	1220	1990
23	1760	2030	1980	895	1200	1610	995	1680	1850	850	1220	1980
24	1750	2020	1910	1020	1120	1650	1030	1830	1970	990	1210	2000
25	1780	2020	1850	922	1160	1720	994	1670	1890	1080	1210	2030
26	1780	2000	1890	926	1090	1640	1200	1680	2000	1110	1240	2040
27	1790	1960	1800	1000	1100	1640	1260	1700	1980	1140	1280	2060
28	1750	1970	1960	1020	1300	1620	1530	1650	1890	1110	1320	2060
29	1640	1940	1960	1130	--	1670	1240	1740	2050	1120	1290	2080
30	1580	1960	1980	1230	--	1750	1210	1750	1980	1120	1360	2060
31	1750	--	2000	1250	--	1710	--	1760	--	1130	1480	--
MONTH	1700	1760	1910	1690	1410	1400	1520	1580	1830	1130	1140	1710

YEAR: MAX - 2620; MIN - 726; MEAN - 1570

(continued)

TABLE 5-1 (continued)

CHEYENNE RIVER BASIN
06428500 BELLE FOURCHE RIVER AT WYOMING-SOUTH DAKOTA STATE LINE

TEMPERATURE (°C) OF WATER, WATER YEAR OCTOBER 1973 TO SEPTEMBER 1974
(ONCE-DAILY MEASUREMENT)

DAY	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
1	19.0	4.0	3.0	0.0	0.0	0.5	10.0	18.0	19.0	26.0	22.0	14.0
2	15.0	3.5	0.5	0.0	0.0	8.0	7.0	12.0	21.0	21.0	22.0	16.5
3	13.0	2.5	0.0	0.0	0.0	6.0	5.5	13.0	22.0	21.5	23.0	17.5
4	14.0	1.0	0.0	0.0	0.0	8.5	7.0	15.0	22.0	24.0	23.0	19.0
5	14.0	0.5	0.0	0.0	0.0	4.0	8.0	18.0	18.0	25.0	24.0	18.0
6	15.0	0.5	0.0	0.0	0.0	1.0	8.0	18.0	20.5	24.5	22.0	22.0
7	15.5	0.0	0.0	0.0	0.0	3.0	8.0	18.0	16.5	27.0	20.0	21.0
8	13.0	0.0	0.0	0.0	0.0	0.5	10.0	19.0	20.0	25.0	20.0	17.0
9	12.0	0.0	0.0	0.0	0.0	3.0	12.0	19.0	18.0	28.0	10.5	14.0
10	5.0	0.5	0.0	0.0	0.0	3.0	8.0	18.0	21.0	25.0	20.5	14.0
11	5.0	2.0	0.0	0.0	0.0	1.0	3.0	16.0	22.0	25.0	20.0	14.0
12	7.0	5.0	0.0	0.0	0.0	0.0	3.5	14.0	25.0	25.0	22.5	14.0
13	12.0	6.5	0.0	0.0	0.0	1.0	5.0	12.0	26.0	29.5	20.0	16.5
14	11.0	5.0	0.0	0.0	0.0	1.0	6.0	11.0	27.0	27.0	20.0	18.0
15	10.5	4.5	0.0	0.0	0.0	4.0	8.0	12.0	27.0	27.0	22.0	20.0
16	14.0	4.0	0.0	0.0	0.0	2.5	8.0		27.0	27.0	22.0	20.0
17	12.0	6.0	0.0	0.0	0.0	7.0	11.0	10.0	26.0	27.0	24.5	19.0
18	13.0	2.0	0.0	0.0	0.0	7.0	15.0	12.0	30.0	27.0	24.0	21.0
19	14.0	0.5	0.0	0.5	0.0	1.0	15.0	15.5	31.0	29.0	24.0	18.0
20	14.0	0.5	0.0	0.5	0.0	0.5	7.0	17.0	30.0	28.5	25.0	25.5
21	14.5	0.0	0.0	0.0	0.0	0.5	10.0	16.0	30.0	28.0	24.0	16.0
22	14.5	0.0	0.0	0.5	0.0	0.5	12.5	17.0	22.0	27.0	23.0	17.0
23	12.0	0-0	0.0	0.0	0.0	0.5	11.0	17.0	27.0	27.0	23.0	17.0
24	12.0	0.0	0.0	0.0	0.0	1.0	15.0	16.0	27.0	27.0	23.5	17.5
25	11.0	0.0	0.0	0.5	0.0	2.0	16.0	21.0	27.0	25.0	25.5	15.0
26	9.0	0.0	0.0	0.0	0.0	4.0	16.0	23.0	27.0	25.0	25.6	15.0
27	9.0	0.0	0.0	0.0	0.0	6.0	14.0	20.0	27.0	26.0	23.0	13.0
28	7.0	0.5	0.0	0.0	0.0	8.0	13.0	22.0	28.0	25.0	21.0	14.0
29	7.0	0.5	0.0	0.0	--	11.0	14.0	14.0	28.0	24.0	19.0	15.0
30	7.0	0.0	0.0	0.0	--	11.0	17.0	15.0	28.0	24.0	16.0	14.0
31	6.5	--	0.0	0.0	--	8.0	--	17.0	--	23.0	16.5	--
MONTH	11.5	1.5	0.0	0.0	0.0	3.5	10.0	16.0	24.5	26.0	22.0	17.0

YEAR: MAX – 31.0; MIN – 0.0; MEAN – 11.0

Eagle Butte lease mentioned earlier was 0.09 inch from March 1974 to June 1975 (100 acre-feet from 22 square miles).

Recharge estimates vary widely. Lowry (1972) estimates that 10 percent of rainfall (1.5 inches) recharges the shallow aquifers. Rechard and Hasfurther (1976) estimate that average annual recharge and runoff do not exceed 1 inch. Other estimates of recharge range from one percent of precipitation (Davis, 1976) to 0.5 inch (U.S. Geological Survey, 1976).

Relative quantities of recharge from interstream areas, stream beds, and stock tanks are now known. Lowry (1972) believes that most recharge takes place in interstream areas. He notes that in the spring the soil thaws and is "frost cultivated." Under this condition, soil permeability is greatly increased and it is possible that large amounts of water infiltrate during the first spring rains.

Recharge through ephemeral or intermittent stream channels is probably significant, especially where well-developed meanders result in stream channel lengths that greatly exceed the length between two points along the longitudinal axis of the floodplain. Recharge by seepage from stock tanks is also likely to be significant, in particular where they are closely spaced along a stream.

The surface hydrology at specific mines depends in a general sense on the position of a site on a watershed. The watershed area that drains through a mine site will decrease as the location of the mine approaches the headwaters of the watershed. Streamflow is ephemeral for small drainage areas and flow volumes are relatively small. The headwaters of the watershed tend to be recharge areas and water tables are relatively deep. At lower elevations on the watershed, streamflow is intermittent and flow volumes can be large; the water table tends to be shallow and groundwater discharges to streams under wet conditions.

Four mines in the monitoring area are located high on their watersheds and drainage areas upstream of the sites tend to be small. These are AMAX Eagle Butte and Carter North Rawhide on the Rawhide Creek watershed and ARCO Black Thunder and Kerr-McGee Jacobs Ranch on Little Thunder Creek watershed (Figure 5-1). The mines on Donkey and Caballo Creeks and the Belle Fourche River watersheds (Figure 5-1) have larger upstream drainage areas.

Table 5-2 summarizes drainage areas for the lease sites and gives mean annual runoff and peak discharge for a 25-year period estimated using Lowham's (1976) methods.

SOILS

This subsection is intended to provide an insight into the relationship of the soil environment to the hydrogeologic framework of the project area which is located within Campbell County. Good quality soil information and data are paramount to the task of completing a comprehensive environmental assessment of the effects of surface coal mining on soil properties. For example, because soil properties will be completely changed by the mining

TABLE 5-2. DRAINAGE AREAS FOR LEASE SITES, MEAN ANNUAL RUNOFF, AND 25-YEAR PEAK DISCHARGE (from Lowham, 1976)

Mine	Hydrologic region (Lowham, 1976)	Stream	Drainage area upstream of lease (mi^2)	Mean annual runoff (ft^3/s)	25-year peak (ft^3/s)
ARCO	2	Little Thunder Creek	58	2.3	1,500
Black Thunder		N. Prong Little Thunder Creek	43	2.0	1,200
Carter	3	Rawhide Creek	60	4.5	3,300
North Rawhide		Little Rawhide Creek	30	3.0	2,800
AMAX	3	Little Rawhide Creek	22	2.6	2,000
Eagle Butte		Dry Fork Little Powder River	17	2.4	1,900
Sun Oil	2	Belle Fourche River	494	8.0	3,000
Kerr-McGee Jacobs Ranch	2	N. Prong Little Thunder Creek	50	2.0	1,200
Wyodak	2	Donkey Creek	100	3.1	1,700

process, knowledge of the premining soil situation is necessary to evaluate the revegetation and infiltration potentials of the spoil material after the land has been disturbed. In some cases, replaced spoil material will be a source of pollution by virtue of its high concentration of soluble salts which may leach to the groundwater.

Existing Soil Environment

Soil formation is largely a function of external processes which alter the parent material of a soil both chemically and physically. Five major factors control the kinds of soil that develop. These are: (1) the nature of the parent material, including its chemical and mineralogical composition, texture, and structure; (2) the climate under which the soil has formed, particularly temperature and precipitation; (3) the living organisms which interact with the soil, especially the native vegetation; (4) the topography of the area when the soil is formed; and (5) the time that the parent materials are subjected to soil formation.

The soils of Campbell County are mostly residual, formed from weathered sedimentary material, mostly sandstone and shale. In general, soils formed from sandstone are of coarse texture (especially in surface horizons), and highly permeable. Soils formed from shales are generally fine textured, relatively impermeable, and consequently poorly leached.

The soils of Campbell County reflect the character of the bedrock to a marked degree. Areas of sandy and medium-textured soils are underlain by sandstone and sandy shale, and heavy soils are underlain by clayey shale.

The sandy loam and loam soils absorb moisture readily. They have friable or only moderately compact subsoils, and they are thicker than the heavy or fine-textured soils. Surface layers are well supplied with organic matter and are neutral or only slightly alkaline. Lower subsoils are calcareous and are represented by a lime carbonate accumulation at depths of 16 to 30 inches.

The gray, heavy clay shale weathers slowly, and the soils developed from it are shallow. The shallow soils have a medium- to fine-textured surface and a dense, compact subsoil. They absorb moisture slowly, and runoff is rapid on the more sloping areas. On the steeper slopes, little or no soil development has taken place due to geologic erosion.

Soils developed from scoria (clinker) were formed in the past by the burning of thick coal beds of the Fort Union Formation, are characterized by a reddish-brown to a light-red friable surface horizon and a red or reddish-brown friable subsoil containing a layer of lime carbonate accumulation.

Alluvial soils are developed from a variety of material washed from the uplands and high landscapes and redeposited along stream courses. They occupy comparatively narrow, elongated, continuous, or broken strips along most of the main drainages. The soils have a grayish-brown to dark grayish-brown friable surface that contains a fair amount of organic matter, and they are calcareous at or near the surface.

Miscellaneous areas of soil include rough broken land, rock land, gullied land, and rock outcrops occupying lands of steep relief characterized by exposed beds of sandstone, shale, and clinker. A complex soil pattern occurs as residual soils between the dissections. The forces of nature are the controlling factors of these landscapes.

The natural vegetation of Campbell County is mainly short grasses common to much of the northern part of the Great Plains region. Some areas in the northern and eastern parts of the County support variable stands of trees. Grass is generally more luxuriant and abundant in the northern than in the southern part of the County due to the slightly greater precipitation in the north. Also, grass grows better on the sandy soils than silty or clayey soils, and better on the smooth areas than on those steeply sloping. Due to the semiarid climate and vegetative conditions, organic matter is accumulated slowly, and soils have developed light-colored surfaces.

Classification of Soil Series of Campbell County—

The present classifications of all soil series published in the 1939 reconnaissance soil survey of Campbell County have been determined, and are included in Table 5-3. As more detailed soil mapping is completed by individual mines, new series are expected to be identified in the County, and the classifications of these series will be included in a subsequent report.

The majority of soil acreage of Campbell County belongs to the soil order aridisols. These are primarily soils of dry places, with an achric epipedon (light-colored surface horizon), with one or more additional diagnostic subsurface horizons. The climatic regime in which aridisols form can be characterized as one in which the potential evapotranspiration greatly exceeds the precipitation during most of the year and no water percolates through the soil.

Because of the limited amount of water available in the profile, the chemical and physical reactions which are important in aridisol profiles are relatively less intense than those in humid regions. Because of this, the soils inherit much of their morphology from the parent material and the lack of leaching has left the profiles with a high base status.

The aridisols are separated from the Inceptisols, soils with one or more diagnostic horizons that are thought to form rather quickly, and that do not represent significant illuviation, eluviation, or extreme weathering, by the circumstance that unless irrigated they are usually dry or have a saturated extract conductivity or more than 2 mmhos/cm at 25° C in the 18- to 50-cm layer (Buol et al., 1973).

The occurrence of an argillic (clay) subsurface horizon relates to age and position on the landscape as well as to soil management. The presence or absence or an argillic horizon in aridisols is used as the basis for dividing the order into two suborders, argids (with argillic horizons) and orthids (without argillic horizons).

TABLE 5-3. SOIL SERIES CLASSIFICATION OF CAMPBELL COUNTY (after Soil Conservation Service, 1939)

Soil Series	Soil Classification
Arvada	Ustollic Natrargid, fine, montmorillonitic, mesic
Banks	Ustic Torriofluvent, sandy, mixed, calcareous mesic
Bridgeport	Fluventic Hapustoll, fine-silty, mixed, mesic
Dillinger	Pachic Hapustoll, fine-loamy, mixed, mesic
Fort Collins	Ustollic Haplargid, fine-loamy, mixed, mesic
Goshen	Pachic Arguistoll, fine-silty, mixed, mesic
Laurel	Aquollic Salorthid, fine-loamy, mixed, mesic
McKenzie	Typic Haplaquept, fine, montmorillonitic (calcareous), frigid
Manvel	Ustic Torriorthenth, fine-silty, mixed (calcareous), mesic
Pierre	Usteric Camborthid, very-fine, montmorillonitic, mesic
Renohill	Ustollic Haplargid, fine, montmorillonitic, mesic
Rough Broken Land	Unclassified and Ustic Torriorthenths, loamy and clayey, montmorillonitic, calcareous, mesic and shallow
Sarpy	Typic Udipsamment, mixed, mesic
Searing	Ustollic Haplargid, fine-loamy, mixed mesic
Terry	Ustollic Haplargid, coarse-loamy, mixed, mesic
Ulm	Ustollic Haplargid, fine-loamy, mixed, mesic
Wibaux	Ustic Torriorthenth, loamy-skeletal over fragmental, mixed mesic

The argids have formed on the oldest geomorphic surfaces, as on the crests of alluvial fans. Orthids are found on geologically younger side slopes and surfaces of intermediate age (Figure 5-8). Soils of the youngest surfaces in the dry region, both the steep mountain slopes and recent alluvial bottoms, have not developed any diagnostic subsurface horizons and are classified as entisols.

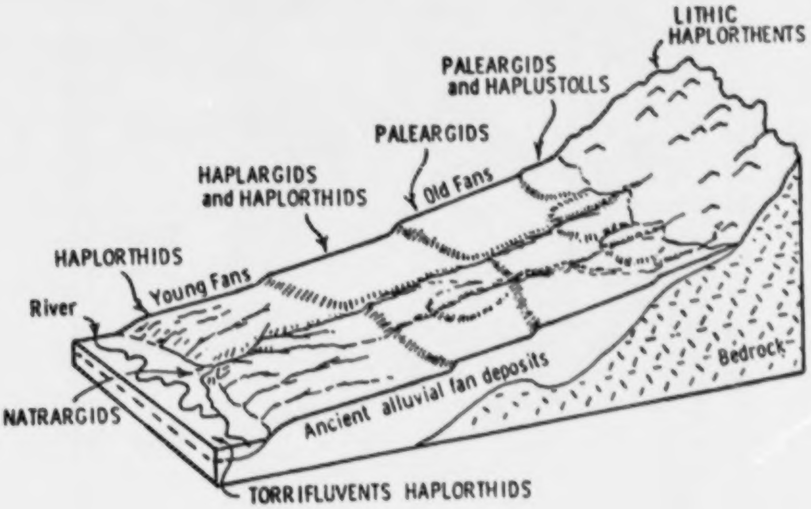

LITHIC HAPLORTHENTS
PALEARGIDS and HAPLUSTOLLS
PALEARGIDS
Old Fans
HAPLARGIDS and HAPLORTHIDS
HAPLORTHIDS
Young Fans
River
NATRARGIDS
Ancient alluvial fan deposits
Bedrock
TORRIFLUVENTS HAPLORTHIDS

Figure 5-8. Block diagram showing positions of some major kinds of aridisols and their associates (after Buol et al., 1973).

Major Soil Associations of Campbell County—

The nature of soil associations is basically a grouping of soils similar to each other according to pattern and position and not on the basis of capability or expected response. Soil associations are named according to the dominant soil series occurring within the delineations. Figure 5-9 illustrates 10 of these associations.

The soil survey of Campbell County separates soils into six groups for purposes of discussion, based on the soils' position on the landscape and the parent material from which they were derived. Their divisions include: soils of the uplands and terraces derived from sandy and slightly silty shales; soils of the uplands and terraces derived from gray clayey shales and clays; soils of the uplands and terraces derived from dark-gray Pierre shale; soils of the uplands derived from sandstone; soils of the uplands and terraces derived from red, burned shale (scoria); and soils of the bottom lands.

Soils of the uplands and terraces derived from sandy and slightly silty shales—The soils of this group include the Ulm, Fort Collins, Goshen, and

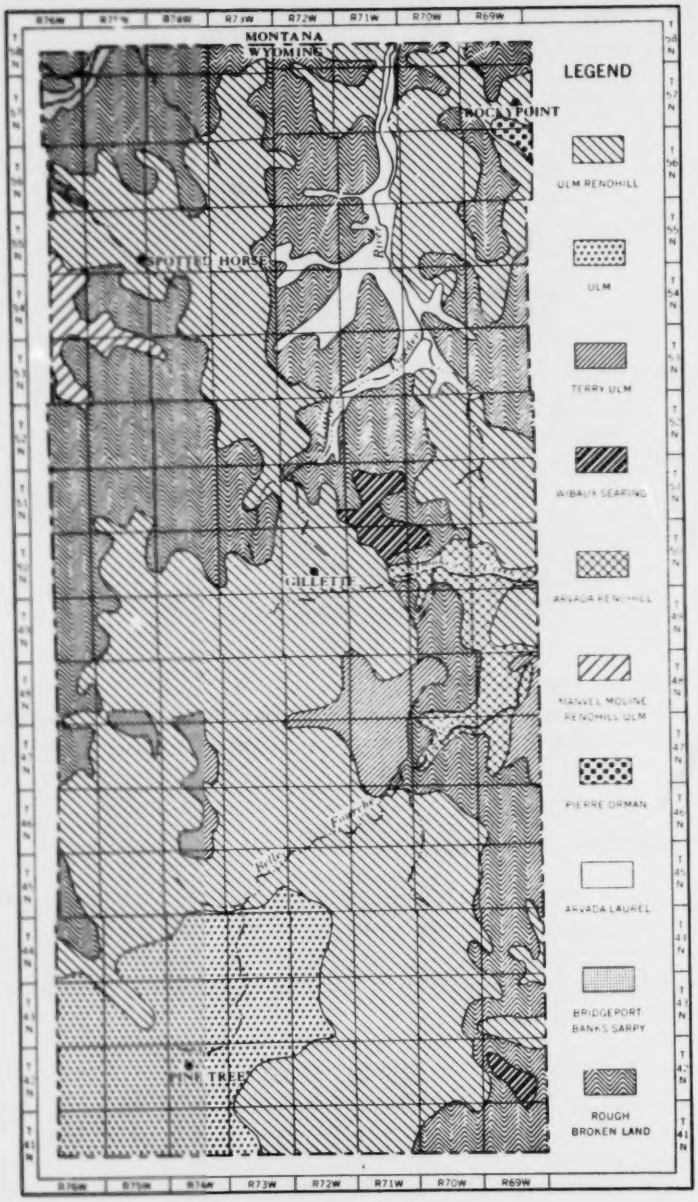

MONTANA
WYOMING
ROCKY POINT
SPOTTED HORSE
GILLETTE
PINE TREE
R76W
R75W
R74W
R73W
R72W
R71W
R70W
R69W
LEGEND
ULM RENOHILL
ULM
TERRY ULM
WIBAUX SEARING
ARVADA RENOHILL
MANVEL MOLINE RENOHILL ULM
PIERRE ORMAN
ARVADA LAUREL
BRIDGEPORT BANKS SARPY
ROUGH BROKEN LAND

Figure 5-9. Soil associations of Campbell County, Wyoming (Soil Conservation Service, 1939).

Bridgeport, which occupy undulating to gently rolling uplands, colluvial slopes, and nearly level stream terraces. All of them are loamy or slightly sandy in their surface layers, and they are friable and silty or only moderately clayey in their subsoils.

Soils of the uplands and terraces derived from gray clayey shales and clays—The soils of this group—the Renohill, Arvada, Manvel, Moline, and McKenzie—occupy upland areas that are underlain by moderately heavy clayey shale, as well as stream terraces and upland slopes and depressions consisting of alluvium washed chiefly from areas of heavy upland soils.

Renohill soil occupies 24.5 percent of the County. It has a light-colored, moderately friable surface horizon with a somewhat heavy compact, slowly permeable subsoil. Arvada soil occupies 4.2 percent of the County and has a clay pan which causes slow external and internal natural drainage. The McKenzie soil has no surface drainage and occupies playas throughout the County.

Soils of the uplands and terraces derived from dark-gray Pierre shale—The Pierre and Orman are the only soils in this group. They occupy only a small acreage in the northeastern corner of the County near Rocky Point. The internal drainage of these soils is very slow, due to a very dense, compact clay subsoil. Free calcium carbonate ranges from 6 to 15 inches because of this slow drainage. This area is shown in Figure 5-9 as the Pierre-Orman Association.

Soils of the uplands derived from sandstone—The Terry is the only soil series in this group. Terry soil occupies large areas in the central and southern parts of the County and, subsequently, occupies a fair amount of acreage on some of the mine lease sites. It has a moderately sandy to sandy surface horizon and a sandy subsoil. Due to its rapid internal drainage, it is leached of calcium carbonate to a depth of 25 to 50 inches.

Soils of the uplands and terraces derived from red, burned shale (scoria)—The soils of this group include the Searing, Wibaux, and Dillinger. They have formed from scoria, the red, burned shale that resulted from the burning of thick coal beds of the Fort Union Formation in the past.

The soils are friable and generally shallow to bedrock, with medium to rapid internal drainage.

Soils of the bottom lands—The soils of the bottom lands are the Banks, Laurel, and Sarpy. They are on floodplains of various widths that have developed along practically all of the creeks and rivers. Many mine lease sites have creeks or rivers which transect them, giving rise to soils of these types on their properties.

The Banks and Sarpy soils have rapid internal drainage, but the Banks is calcareous whereas the Sarpy is not. The Laurel soil is medium textured, light grayish brown, friable, and calcareous.

Salinity and Alkalinity in Soils—

Many soils in the western United States are affected by excessive concentrations of either soluble salts or exchangeable sodium, or both, resulting in reduced crop production.

The term "saline soil" is defined as a nonsodic soil containing soluble salts in such quantities that they interfere with growth of most plants. The exchangeable sodium percentage (ESP) is less than 15 and the electrical conductivity of the saturated soil paste extract (ECe) is greater than 4 mmhos/cm. The term "sodic soil" (formerly called "alkali soil") refers to a condition in which the soil contains sufficient exchangeable sodium to interfere with the growth of most crop plants, either with or without appreciable quantities of soluble salts. Another condition which commonly occurs in semiarid and arid regions is known as a "non-saline-sodic soil." This type of soil contains sufficient exchangeable sodium to interfere with the growth of most crops and does not contain appreciable quantities of soluble salt. The ESP is greater than 15 and the ECe is less than 4 mmhos/cm. The pH usually is greater than 8.5 (Fuller and Halderman, 1975).

Rhoades (1974) has indicated that the primary sources of soluble salts in agricultural soils are: (1) irrigation waters, (2) salt deposits present in soil parent materials, (3) agricultural drainage waters (both surface and subsurface) drainage from upper-lying lands, and (4) shallow water tables. Rhoades (1974) has listed additional sources of soluble salts, termed "secondary" which include: (5) fertilizers, agricultural amendments, or livestock and poultry manures applied to soils, (6) weathering soil minerals, and (7) rain and snow.

Undoubtedly, several of these sources have contributed to the formation of saline and sodic soils in Campbell County in the past, and will contribute to salt accumulation in the future once spoils have been reclaimed.

Of primary concern to a monitoring program is the pollution potential of these saline and sodic soils as a consequence of their disruption and placement in designated burial sites. Because of the importance of these types of soil material as a source of pollution, this section of the report attempts to characterize the soils of Campbell County which exhibit saline and/or sodic soil conditions, based largely on information available in the 1939 reconnaissance soil survey of Campbell County, and a meager amount of laboratory data. It should be noted that all of the land mapped as a soil series and designated as exhibiting saline and/or sodic soil conditions, may not in fact possess these properties. In many instances these phenomena are highly localized in various microenvironments, largely a function of position on the landscape, proximity to the water table, and the nature of the parent material.

Arvada series—Saline drainage water accumulates on this soil, and on its evaporation, a sodic salt deposit results. This soil possesses a compact claypan-like subsoil which causes poor drainage by impeding the downward movement of water and thus contributing to the salinization and alkalization of the soil. Calcium carbonate is present in the subsoil in streaks and seams which occur below an average depth of 15 inches. In some areas of the County, wind erosion has removed the surface soil and exposed the heavy, saline clay subsoil, resulting in scabby spots, barren of vegetation or marked by the presence of salt-tolerant plants such as greasewood and saltgrass.

This soil occupies extensive areas throughout the County and occurs on all coal leases and, therefore, is considered a likely candidate for burial in reclamation operations.

Bridgeport series—This soil is calcareous at or near the surface downward, but has no horizon of calcium carbonate accumulation. Some sodic salts, seldom concentrated enough to injure vegetation, are present in nearly all areas where this soil has been mapped, with the areas most strongly affected occuring along Wildcat Creek. Due to the small total area that this soil series occupies, it is not considered a potential source of pollution.

Laurel series—The soil of the Laurel series has developed from calcareous recent alluvium washed from the soils of the sandstone, shale, and limestone uplands, therefore, it has accumulated soluble salts.

The lower parts of the subsoil and substratum are splotched and streaked with white accumulations of calcium carbonate and other salts to a depth of 5 feet or more. This soil is not extensive in the County, and occurs mainly along the Belle Fourche River and South Fork Wildcat, Horse, and Bitter Creeks, with small areas along many of the small drains.

Manvel series—Many small areas of soil included with this soil type contain free salts. The so-called "white salts," chlorides, and sulfates, are most common, especially in the surface horizon; but sodium carbonate, or "black alkali," occurs in small quantities in the subsoil and substrata.

McKenzie series—This soil varies widely in stage of development, as is indicated by its layers of calcium carbonate accumulation. In some places this carbonate-bearing layer is within a few inches of the surface; in others it may be at depths as great as 3 feet. This soil occupies playas or depressions in the central and south-central parts of the County and, therefore, has been mapped on several lease sites.

Orman series—The surface soil of this series is commonly leached free of salts, but they have accumulated in numerous flat or slightly depressed spots in quantities sufficient to injure certain types of vegetation or prevent their growth. Some crystalline gypsum and other salts are present in the subsoil in most areas.

Because only a few small areas of Orman clay are mapped in the County, it is not considered a significant pollution source.

Pierre clay—The surface horizon of this soil is noncalcareous, with the subsoil being a compact cloddy clay in which some white streaks of calcium carbonate have accumulated. Some of the shale contains little calcium carbonate, and the soil developed from it is noncalcareous or only lightly calcareous. Gypsum is usually present in varying quantities in the lower part of the subsoil and in the substratum.

Renohill series—The upper subsoil of this series typically contains no free calcium carbonate, but the lower subsoil is more friable and has an abundance of calcium carbonate.

Ulm series—Calcium carbonate has accumulated in the lower subsoil of this series but, because they have adequate drainage and excellent tilth, they are considered some of the most productive soils of the uplands.

Hydrologic Soil Classification

Soil properties influence the process of generation of runoff from rainfall. Runoff from a plot on a small natural watershed occurs when the rate of rainfall exceeds the infiltration capacity. Kohnke (1968) has indicated that the actual relationship of these three hydrologic factors is complicated by interception storage, depression storage, and surface detention of the water and that, if considered over longer periods, evaporation and transpiration as well as condensation and adsorption must also be considered.

Although such a complex analysis of surface runoff is not warranted at this time, an attempt has been made to at least provide general insight into this parameter, by delimiting areas of soil on particular watersheds that exhibit similar infiltration characteristics.

This task was accomplished by first defining a watershed which encompasses (all or in part) the coal leases to be monitored. The defined watersheds were then superimposed on soil maps corresponding to the same areas of interest, thereby yielding a soils map of the watershed. Once this was accomplished, the soils occupying a given watershed were classified in hydrologic soil groups as defined by Soil Conservation Service (SCS) soil scientists. The hydrologic soil groups are as follows:

- (Low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well-to-excessively drained sands or gravels. These soils have a high rate of water transmission.

- Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep-to-deep, moderately well-to-well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

- Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

- (High runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

The hydrologic classification of soils occurring in Campbell County was derived from the SCS National Engineering Handbook (1971), and is presented in Table 5-4. Areal extents of the four soil groups were determined for each of the five watersheds by placing a grid (or "dot counter") over the map, determining the number of grid intersections falling on each group, and then computing the particular group percentages of the entire watershed. These percentages are listed in Table 5-5 and are considered to be approximate.

TABLE 5-4. HYDROLOGIC SOIL CLASSIFICATIONS

Soil series	Map symbol	Hydrologic soil classification
Arvada	Aa, Ab, Ac	D
Banks	Ba	A
Bridgeport	Bb	B
Dillinger	Da	B
Fort Collins	Fa, Fb	B
Goshen	Ga, Gb	B
Laurel	La	C
McKenzie	Mb	D
Manvel-Moline	Ma	C
Orman	Oa	C
Pierre	Pa	D
Renohill	Ra, Rb, Rc, Rd, Re	C
Rough Broken Land	Rf, Rg, Rh	D
Sarpy	Sa	A
Searing	Sb	B
Terry	Ta, Tb	B
Ulm	Ua, Ub, Uc, Ud, Ue	B
Wibaux-Searing	Wa	C

TABLE 5-5. APPROXIMATE AREAL PERCENTAGES OF HYDROLOGIC SOIL GROUPS

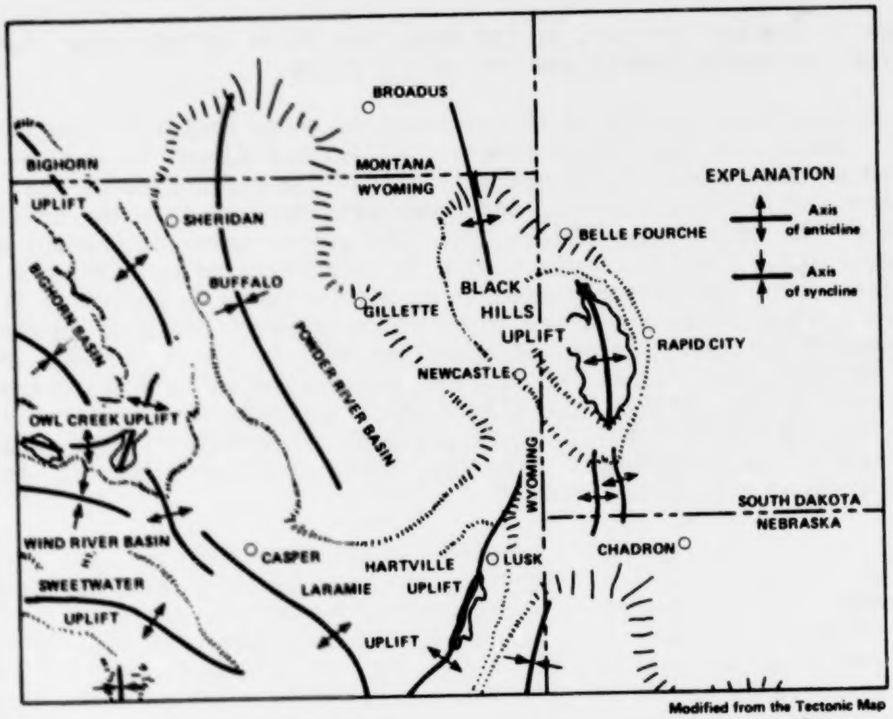
Watershed	Areal percent
Belle Fourche River	A - 1.7
	B - 56.8
	C - 22.3
	D - 19.2
Caballo Creek	A - 0.5
	B - 42.0
	C - 39.2
	D - 18.3
Donkey Creek	B - 33.4
	C - 30.6
	D - 36.2
Little Thunder Creek	B - 41.1
	C - 26.3
	D - 32.6
Rawhide Creek	B - 37.7
	C - 23.9
	D - 38.4

GEOLOGY

Regional Geology

The study area is located along the eastern edge of the Powder River Basin, a structural and topographic basin which is approximately 250 miles long and 100 miles wide. The basin is bounded by the Bighorn Mountains on the west, the Black Hills Uplift on the east, and a series of arches and uplifts to the south. As shown in Figure 5-10, the basin extends north into Montana. The thick assemblage of sedimentary rocks underlying the basin reaches nearly 12,000 feet in thickness. Paleozoic sediments rest on crystalline Pre-Cambrian rocks. Although there are at least six unconformities in the sequence, the Paleozoic assemblages are approximately 2,500 feet thick (U.S. Geological Survey, 1974a). Most are either limey sandstones, sandstones, or marine limestones. These formations have outcrops in the Bighorn Mountains to the west.

The Mesozoic accumulations in the Eastern Powder River Basin include shales and claystones which were deposited in the Upper Jurassic and Cretaceous periods. Thin conglomerate sequences and one thin limestone unit are also present. The Mesozoic sequence is about 7,000 feet thick in the study area.


BROADUS
MONTANA
WYOMING
BIGHORN
UPLIFT
SHERIDAN
BIGHORN BASIN
BUFFALO
POWDER RIVER BASIN
GILLETTE
BLACK
HILLS
UPLIFT
BELLE FOURCHE
RAPID CITY
NEWCASTLE
OWL CREEK UPLIFT
WYOMING
SOUTH DAKOTA
NEBRASKA
WIND RIVER BASIN
SWEETWATER
UPLIFT
CASPER
LARAMIE
UPLIFT
HARTVILLE
UPLIFT
LUSK
CHADRON
EXPLANATION
Axis of anticline
Axis of syncline

Modified from the Tectonic Map of the United States.

Figure 5-10. Generalized map showing the Powder River Basin in relation to nearby structural features.

This study is primarily concerned with Cenozoic deposits. Tertiary deposits are the most important in that they contain the coal formations and that they outcrop in the study area. In the study area, the Tertiary deposits are approximately 2,500 feet thick, and consist of siltstones, claystones, coal beds, and discontinuous sandstones. Quaternary deposits consist of alluvium and colluvium which occur in local drainage areas.

The two formations of particular importance to this study are the Wasatch and Fort Union.

An angular unconformity exists between these formations in the study area. This is probably indicative of a large surge of Laramide uplift. The lower Wasatch is composed of arkosic sands which were probably derived from uplifted Pre-Cambrian strata (Davis, 1976). The study area is approximately 75 miles from the Bighorn range and most of the Wasatch rocks outcropping out in the area are sandy shales and shales. Local lenticular sandstone units found in the area are indicative of paleo-stream channels. Small swamps existed during the Eocene period in this area, and some thin to moderately thick coal beds exist in the Wasatch. These coals, with the exception of the Felix coal, are not as continuous as the Fort Union coals. The Wasatch Formation crops out in the western part of the study area. The Fort Union outcrops in the eastern part of the area, and it is in this area that the major coal stripping operations are taking place.

The Fort Union Formation is comprised of three members: the Tullock, the Lebo Shale, and the Tongue River. The Tullock member is predominately composed of shales and claystones with a few thin discontinuous coal beds in its upper part. These fine-grained rocks were derived from the uplifted margins of the Powder River Basin after the gentle Laramide Orogeny of late Cretaceous age. The Lebo Shale member is characterized by a thick mudstone assemblage which was probably associated with a surge in uplift of the Bighorns. Again there are a few thin, discontinuous coal beds in this member. The Tongue River member comprises more than half of the Fort Union Formation (1,500 to 1,800 feet thick) and has the most persistent and thick coal seams in the area (Glass, 1976). The strata which separate the various coal beds are shales and clays, although there are many discontinuous sandy areas which indicate past drainages. The Fort Union coals are shown in the fence diagram presented as Figure 5-11.

Geologic history contains numerous instances where coal beds have burned. When the coal outcrop is ignited, the burn proceeds downdip under the overburden. The overburden is subsequently "baked" and its geologic character is altered. The new rock, called scoria or clinker, is usually reddish orange and is quite resistant to weathering. As a result, many of the hills in the area are capped by clinker zones. Field observation shows that the clinker reaches a considerable depth and eventually reaches a contact with the coal seam.

Structure

The Powder River Basin is an asymmetric, gently sloping structural and topographic depression in northeastern Wyoming. In the study area, dips range from three to five degrees to the west. There are few faults or folds of any significance in the area. However, large scale compaction structures exist in the northern part of the area. These structures were discussed in a paper by Law (1976). As the coal beds are compacted by overburden, buried stream channel clastics experience less compaction and exist as topographically high areas. Law (1976) shows that small normal faults occur in these areas.

Geologic History

The geologic history of the region was as follows:

- There was Paleozoic accumulation of limestone, sandstone and shale in shallow seas as the basin was slowly downwarped.
- Transgression of the sea during the Mesozoic allowed the deposition of thick shales. Various transgressions and regressions are evident from limestone and conglomeratic phases.

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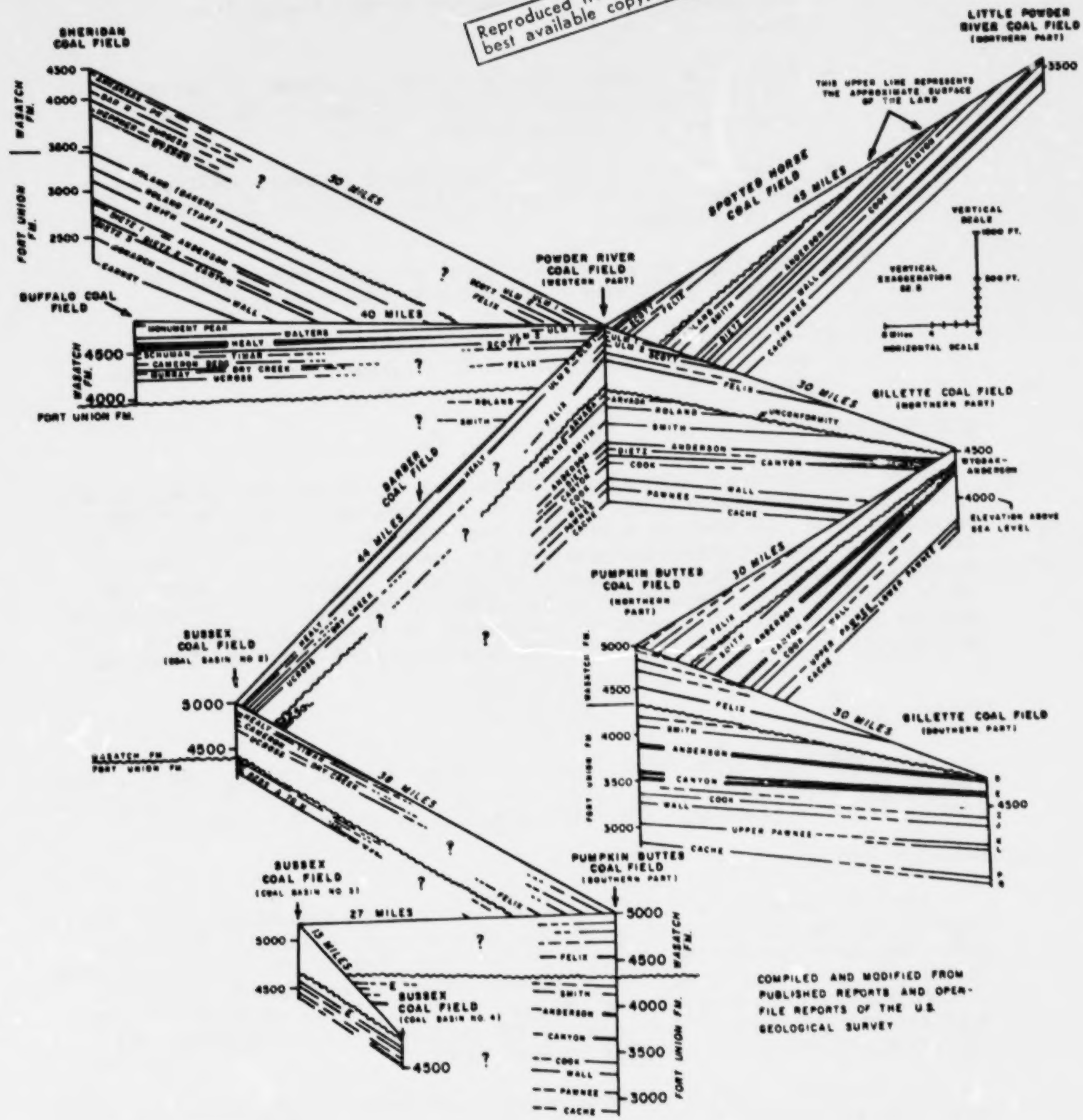

SHERIDAN COAL FIELD
4500
4000
3500
3000
2500
WASATCH FM.
FORT UNION FM.
ROLAND (BAKER)
ROLAND (TAFF)
SMITH
DIETZ 1
ANDERSON
DIETZ 2
DIETZ 3
MONARCH
CANYON
CARNEY
WALL
50 MILES
40 MILES
?
BUFFALO COAL FIELD
MONUMENT PEAK
WALTERS
HEALY
SCHUMAN
TIMAN
CAMERON BEDS
DRY CREEK
MURRAY
UCROSS
FORT UNION FM.
POWDER RIVER COAL FIELD (WESTERN PART)
SCOTT
ULM 1
ULM 2
FELIX
ARVADA
ROLAND
SMITH
DIETZ
ANDERSON
CANYON
COOK
WALL
PAWNEE
CACHE
UNCONFORMITY
LITTLE POWDER RIVER COAL FIELD (NORTHERN PART)
3500
THIS UPPER LINE REPRESENTS THE APPROXIMATE SURFACE OF THE LAND
SPOTTED HORSE COAL FIELD
45 MILES
VERTICAL SCALE
1000 FT.
500 FT.
VERTICAL EXAGGERATION 50 X
0 Miles 4
HORIZONTAL SCALE
30 MILES
GILLETTE COAL FIELD (NORTHERN PART)
4500
WYODAK-ANDERSON
4000
ELEVATION ABOVE SEA LEVEL
BARBER COAL FIELD
44 MILES
PUMPKIN BUTTES COAL FIELD (NORTHERN PART)
5000
4500
4000
3500
3000
UPPER PAWNEE
LOWER PAWNEE
GILLETTE COAL FIELD (SOUTHERN PART)
SUSSEX COAL FIELD (COAL BASIN NO 2)
5000
4500
WASATCH FM
FORT UNION FM
38 MILES
PUMPKIN BUTTES COAL FIELD (SOUTHERN PART)
SUSSEX COAL FIELD (COAL BASIN NO 3)
27 MILES
13 MILES
SUSSEX COAL FIELD (COAL BASIN NO 4)
E
COMPILED AND MODIFIED FROM PUBLISHED REPORTS AND OPEN-FILE REPORTS OF THE U.S. GEOLOGICAL SURVEY

Figure 5-11. Correlation of coal beds in the Powder River Coal Basin (Glass, 1976).

- The Laramide Orogeny shaped the current Powder River Basin

- During the Orogeny, Paleocene swamps occupied the basin, and thick accumulations of coal developed in the Tongue River Member of the Fort Union Formation.

- Wasatch Formation clastics originated in areas uplifted by the final Laramide activity. A few thin coal beds occur in this formation.

- The Oligocene White River Formation contained terrestrial clastics which have been eroded in the study area.

- Recent conditions have shaped the surface topography and have allowed the deposition of alluvium in surface drainage areas.

HYDROGEOLOGY

The hydrogeology of the project study area is complex and subject to many local variations. For this reason, a general overview of the hydrogeology is presented first, followed by a mine-by-mine, site-specific discussion. The data and information presented here are a summary of published records submitted to Federal agencies by the mining companies, supplemented with some field observations. The quality of this report, therefore, is limited to the quality of information released by the mines. Up-to-date hydrogeologic information must be made available for TEMPO to evaluate pollutant relationships with local hydrogeology.

Shallow Aquifers

Five different types of shallow aquifers exist in the study area: alluvial, Wasatch Formation, scoria, coal seam, and the Fort Union aquifers below the coal seams. Their relationships are fairly complex, as shown in Figure 5-12.

Alluvial Aquifers—

Alluvial material is found in stream drainages throughout the study area. Most of the unconsolidated alluviums are fine grained, subangular sediments which have been derived from Wasatch or Fort Union shales and sandstones. Some larger clasts of locally derived clinker detritus may be present. Alluvial transmissivities may range around 500 gpd/ft (Davis, 1976) but they have not been extensively tested. The units seldom exceed 50 feet of thickness and storage coefficients are probably 10^{-2} to 10^{-1}.

The alluvial aquifers can have recharge-discharge relationships with every other type of aquifer in the area. The interaction of surface water and groundwater systems in the alluvium is very important, but is not well understood.

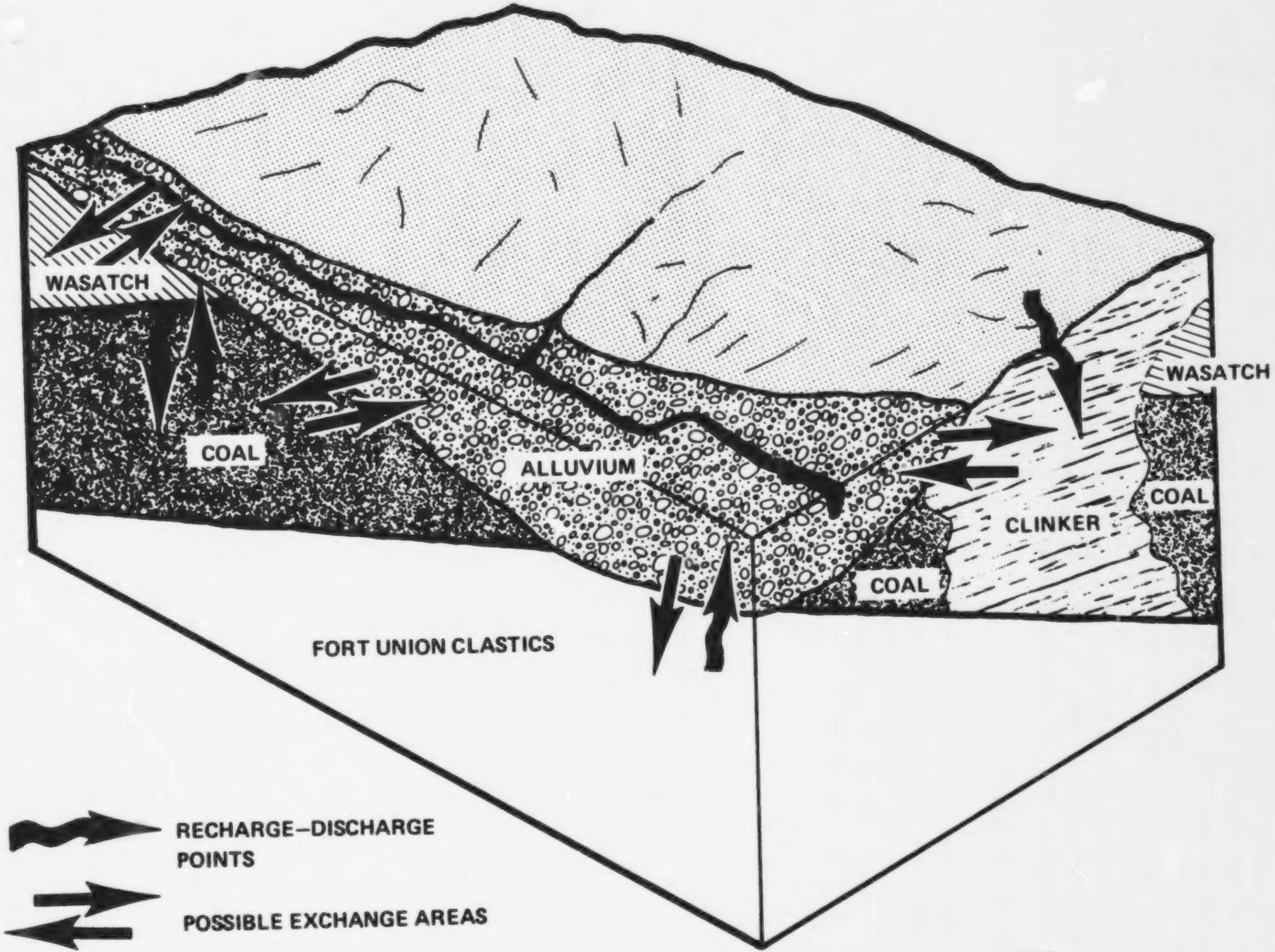

WASATCH
COAL
ALLUVIUM
WASATCH
COAL
CLINKER
COAL
FORT UNION CLASTICS
RECHARGE–DISCHARGE POINTS
POSSIBLE EXCHANGE AREAS

Figure 5-12. Aquifer relationships (modified from Davis, 1976).

Surface runoff associated with precipitation recharges the alluvium and it may be transmitted to the coal aquifers, or it may move downgradient in the stream channel and eventually be evaporated. During dry periods, the alluvial aquifers are probably recharged from the beds which overlie the coal. This water seldom appears as base flow in the stream, as it probably moves down the streambed as underflow. Much of the water in the alluvium is discharged by evaporation. Water budget studies should be used to try to quantify the volume of water which is lost through this process, although such a study would have to quantify all of the inflows to and outflows from the other aquifer systems. This might prove to be a very difficult process. Well yields from alluvial aquifers vary greatly due to local differences in permeability and aquifer thickness, and there are relatively few wells in the alluvial systems.

Wasatch Formation Aquifers —

These units are quite variable, and can be good to very poor aquifers. There are many paleochannels where relatively permeable sandstones transmit enough water for successful water wells. Elsewhere, numerous clay layers can effectively perch water. These layers make it very difficult to describe regional aquifer characteristics. Also, numerous thin coal beds are located in the Wasatch formation. The thickness of the Wasatch formation ranges from near zero in the coal outcrop regions to approximately 300 feet at the western edge of the study area.

Although the units dip to the west, local topography exerts a large influence on groundwater flow directions. Approximately 1 to 5 percent of annual rainfall is estimated to reach Wasatch groundwater systems. This water generally moves according to gradients which lead to local drainages. Numerous small stock wells have openings in these strata, and most water level maps of the area reflect the effects of gradients established by local drainages. In addition to rainfall infiltration, the units may be recharged by water in alluvial channels in the western part of the study area, and by water transmitted through clinker-overburden contacts. Natural discharge occurs in the alluvial valleys in the eastern part of the study area and downward leakage accounts for the remainder of the natural discharge. Most wells in the Wasatch are low yield stock wells, but wells which penetrate sandstone strata might produce up to 100 gpm. The percentage of the total discharge attributable to extraction from wells is not known, although it might be significant.

Scoria Aquifers —

The scoria (clinker) areas are probably the most interesting hydrogeologic phenomena in the study area. When shales which overlie coal beds are baked, a scoria-type rock is formed. These expanded rock masses can collapse into the void left by the burned coal. Also, gases produced during the burn will rise, and some of the scoria are vesicular. The result of these combined effects can be a very permeable aquifer. Coal outcrop fires were quite extensive in the past, and the clinker zones in the study area are fairly continuous and may extend laterally underground for as much as a mile (U.S. Geological Survey, 1974a). Transmissivities can range from 10^2 to 10^6 gpd/ft (Davis, 1976), and there is evidence to support values near the upper end of the range. A Wyoming Highway Department pumping test referred to in Rahn (1976) reported specific capacities of 18 gpm/ft. Other estimates of clinker transmissivity (Dr. J. Harshbarger, University of Arizona, oral communication, 1977) are on the order of at least 10^6 gpd/ft. Storage coefficients generally reflect unconfined conditions and probably range around 10^{-1}.

The recharge-discharge relationships of the scoria aquifers are not well understood. Although they have extensive outcrop areas, many areas may have developed soil horizons with large clay fractions and poor infiltration potential. The fact that most of the areas are hilly would indicate fairly rapid runoff of surface water, also lowering infiltration potential. However, some scoria areas intersect alluvial valleys. These are probably recharge areas. The water-bearing characteristics of the clinker areas indicate that they do receive substantial recharge, and the exact mechanisms should be closely studied in the future. Scoria discharge areas depend upon the local arrangement of the system. The coal seams probably receive some amount of clinker discharge. In areas where alluvium is intercepted, the recharge-discharge relationship depends on the head relationships of the two systems. When the clinker has more head, it will discharge into the alluvium, and the water may eventually evaporate. The converse situation would exist when the alluvium has more head than the clinker. Minor amounts of scoria discharge may leak into the lower members of the Fort Union Formation. Discharge related to human activity is relatively small. In areas where the clinkers are mined for use as road paving materials, there is loss of water from storage. Due to the hard rock character of the clinker, very few wells withdraw water from the scoria aquifers.

Coal Seam Aquifers —

The regional environmental impact statement (U.S. Geological Survey, 1974c) emphasizes the point that the coal seams are the best aquifers in the area. The reason for this observation is that the coals are by far the most regionally extensive sedimentary layers in the basin. The permeability of the coal is due to extensive fractures. Transmissivities range from 10^2 to 10^4 gpd/ft, and are related to the thickness of the coal seam and the extent of local fracturing. Wells in the coal seams seldom yield more than 20 gpm, and most of them range around 10 gpm. Transmissivities and storage coefficients for the coal aquifers vary widely, depending on the nature and occurrence of the fractures in the coal.

The coal seams are near the surface in the eastern part of the study area. Most of the actual outcrop areas have been burned, so clinker zones line the outcrop pattern. These are recharge areas for the coal seam aquifers. The clinker beds are quite permeable, and they may act as "head tanks" above the coals. Also, the coal seams may receive recharge as downward leakage from overlying Wasatch strata. These overlying beds are relatively impermeable and they act as leaky aquitards. The local occurrence of sandy zones in the overburden makes it difficult to discuss regional aquitard characteristics. The coals are also recharged in drainage areas. In the study area, coal seams often lie directly beneath alluvium, and they generally dip away from the drainage (see Figure 5-12). The alluvium receives water from surface events and from local groundwater discharge of the Wasatch beds. The alluvial stream beds are probably very important interchange areas in the groundwater system in the Eastern Powder River Basin.

Natural discharge areas are less obvious than recharge areas. Depth to the coals increases as they dip to the west. Some water is lost as downward leakage to the lower members of the Fort Union Formation. Most of the water in the coal seam generally moves westward under a small gradient under confined or semiconfined conditions. Water wells account for most of the discharge from the coal seam aquifers. Although the overlying sediments may be just as permeable as the coal in some areas (Rahn, 1976), most wells have been completed in the coals because of their local reputation as water-bearing zones. The majority of water wells in the study area are small stock watering wells which are pumped with windmills. There are also a number of domestic wells. Seepage from the coal seams will occur when they are mined. As a rule of thumb, most companies predict that they will have to pump about 70,000 to 120,000 gpd from their pits.

Fort Union Aquifers Below the Coal Seams —

Groundwater occurs at various depths below the Wyodak-Anderson coal seams. Strata immediately beneath the coal seams are predominantly clay-rich, and these units can confine deeper Fort Union water. Most of the mines claim that little or no upward leakage is expected to enter the mine pit through these confining layers. At greater depths, however, aquifers containing relatively good quality water exist. The City of Gillette has many "soft water" wells completed approximately 600 feet below the base of the coal seam. Transmissivities are on the order of 10^4 gpd/ft, and storage coefficients reflect confined conditions. All of the mines are completing their supply wells in these deeper Fort Union aquifers.

These aquifers may receive downward leakage from overlying strata, but their predominant source of recharge is from their outcrop areas to the east. Discharges from the aquifers include pumpage, and upward or downward leakage to adjacent aquifers.

Site Specific Hydrogeology

Hydrogeologic descriptions of each of the seven mines in the project area follow.

AMAX Belle Ayr South —

The Belle Ayr South mine is located approximately 20 miles south of Gillette. The mine began producing coal in 1975. Hydrogeologic changes at this mine may be indicative of similar changes to watch for at the other mines in the area.

Wasatch overburden in the vicinity of the Belle Ayr South mine is selectively saturated with groundwater. Wet areas are characterized by sandstone lithologies, while the dry areas are shales or siltstones. The Wasatch Formation thickens to the west of the present pit, and it is anticipated that more saturated sandstone paleochannels will be encountered as mining continues. Pump test data for Wasatch wells are shown in Table 5-6 and Figure 5-13. The low transmissivities and semiconfined storage coefficients are similar to the results of other pump tests in Wasatch wells.

TABLE 5-6. AQUIFER PARAMETERS IN THE BELLE AYR MINE VICINITY (AMAX Coal Co., 1977)

Well No.	Aquifer completed	Azimuth to observation well	Pump test results		Transmissivity (gpd/ft) recharge (in/yr)	Calculated recharge (in/yr)	Calculated porosity	Aquifer thickness (ft)
			Transmissivity (gpd/ft)	Storage coefficients				
N-1	Wyodak	-	-	-	524	-	0.12	65
N-3	Wyodak	N – S	1353	0.01	9894	0.14	NA	62
N-5	Wasatch	E – W	6175	0.0018	187	33.0	0.04	100
N-6	Wyodak	-	-	-	2755	-	-	65
N-9	Open hole through Wyodak (uncased)	-	-	-	1140	-	-	95?
N-11	Wasatch	-	-	-	1959	-	-	50
N-13	Wasatch	N – S	3495	0.0054	2368	1.48	-	54
N-14	Open hole through Wyodak (uncased)	-	-	-	4133	-	-	80
481	Wyodak	-	-	-	1677	-	0.13	60
WRRI-7A	Fort Union	E – W	1528	0.0022	488	3.13	0.12	60
WRRI-10	Wyodak	E – W	3542	0.0038	-	-	-	90
	Average values	-	3218	0.0046	2512	-	-	-

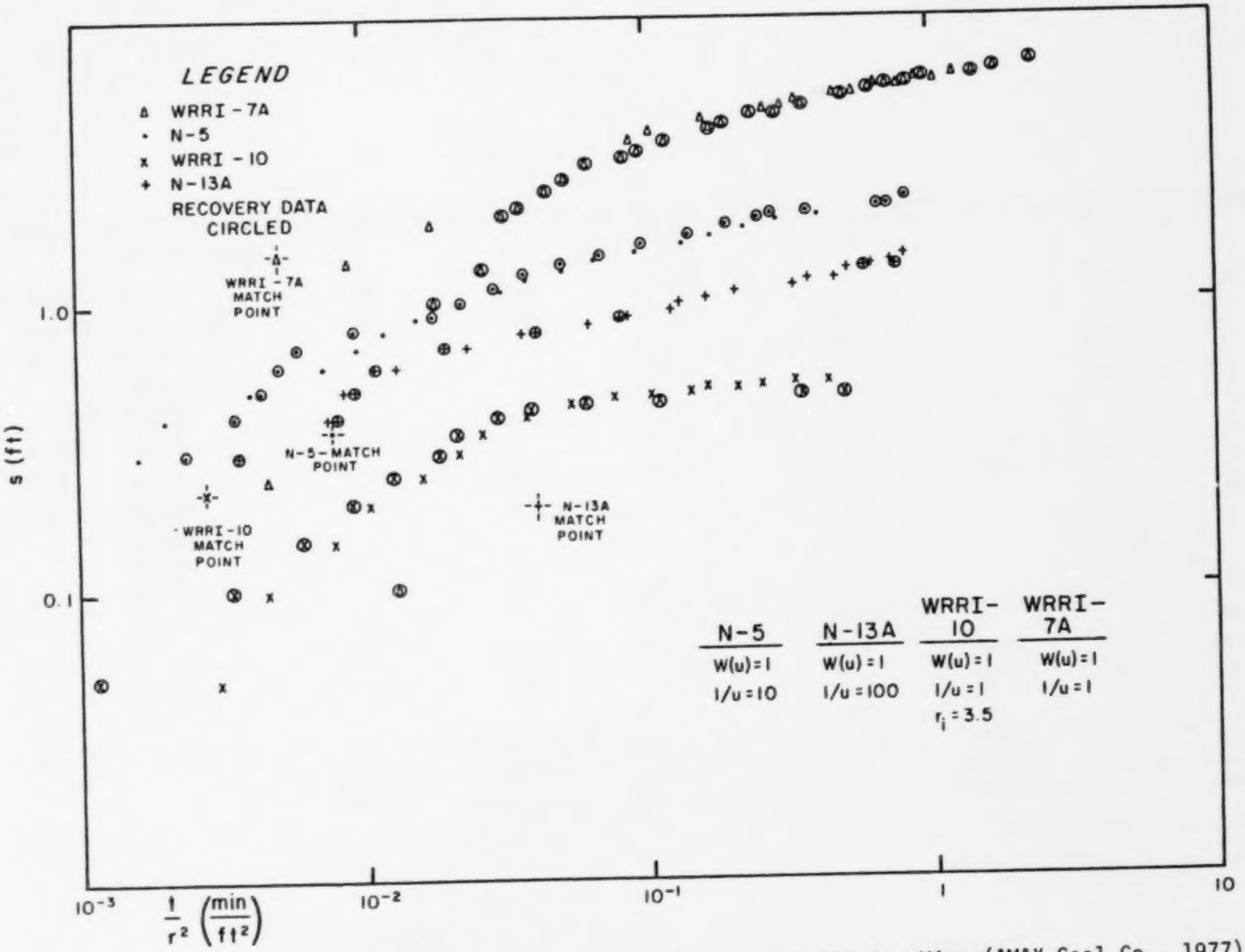


Figure 5-13. Plots of results from four pump tests near Belle Ayr Mine (AMAX Coal Co., 1977).

Scoria aquifers are locally significant at this mine. Initial cuts into scoria hills for road gravel encountered water and some water is still being pumped from these areas. AMAX is trying to determine the source of this water in order to evaluate the problem (Ted Terrell, AMAX Coal Co., personal communication, 1977). As mining progresses to the west, no significant scoria areas will be encountered and large inflows to the pit from clinkers are not anticipated.

Figure 5-14 is an isopach map of the alluviated areas along Caballo Creek. The alluvium is seldom thicker than 30 feet, with channel widths ranging from 400 to 2,000 feet (AMAX Coal Co., 1977). AMAX has not published the results of any aquifer tests in the alluvium, except to say that such tests show low permeabilities in the alluvium (AMAX Coal Co., 1977).

The coal seams at Belle Ayr South are moist and some of the fractures conduct significant groundwater flow. Field observations note that at the highwall some fractures discharged approximately 15 gpm. AMAX estimates that approximately 100,000 gpd is pumped from the mine (U.S. Geological Survey, 1975). Coal transmissivities and storage coefficients are given in Table 5-6. Such data are local, and will vary with the number of water-bearing fractures which are penetrated.

Well hydrographs for wells in the Wasatch Formation, the coals, and the alluvium are shown in Figures 5-15 through 5-17. Monitoring wells have been installed by the Wyoming Water Resources Institute at the locations described in Table 5-7.

AMAX Eagle Butte —

The Eagle Butte Mine, located just south of the North Rawhide Mine, has a hydrogeologic situation similar to that of the Rawhide Mine. Groundwater occurs above, below, and in the coal seams, as well as in the alluvial areas and in clinker deposits.

The Wasatch Formation contains some groundwater but cannot be thought of as a regional aquifer. Some overburden wells drilled on the lease, such as wells D-534 and C-592, encountered no water in the Wasatch Formation (see Figures 5-18 and 5-19). As shown on the geologic cross-sections, Figures 5-18 and 5-19, lithologies within the Wasatch Formation are discontinuous. Therefore, the aquifer parameters shown in Table 5-8 are probably not representative of the entire Wasatch Formation. Transmissivities listed for two pump tests were 30 gpd/ft and 177 gpd/ft. More tests are needed to verify these results. Storage coefficients will most often reflect unconfined conditions, although the 0.003 figure of Table 5-8 indicates some locally confined areas.

Scoria deposits are located at most of the topographically high areas on the Eagle Butte lease area, and adjacent to the coal, as shown on Figures 5-18 and 5-19. AMAX has not indicated the extent of their drilling program in scoria, nor have they discussed the percentage of scoria areas which are wet or dry. The pump test on well GN-8, which penetrated a scoria zone, yielded relatively high transmissivities (140,000 gpd/ft) as shown in Table 5-8. Storage coefficients should reflect unconfined conditions.

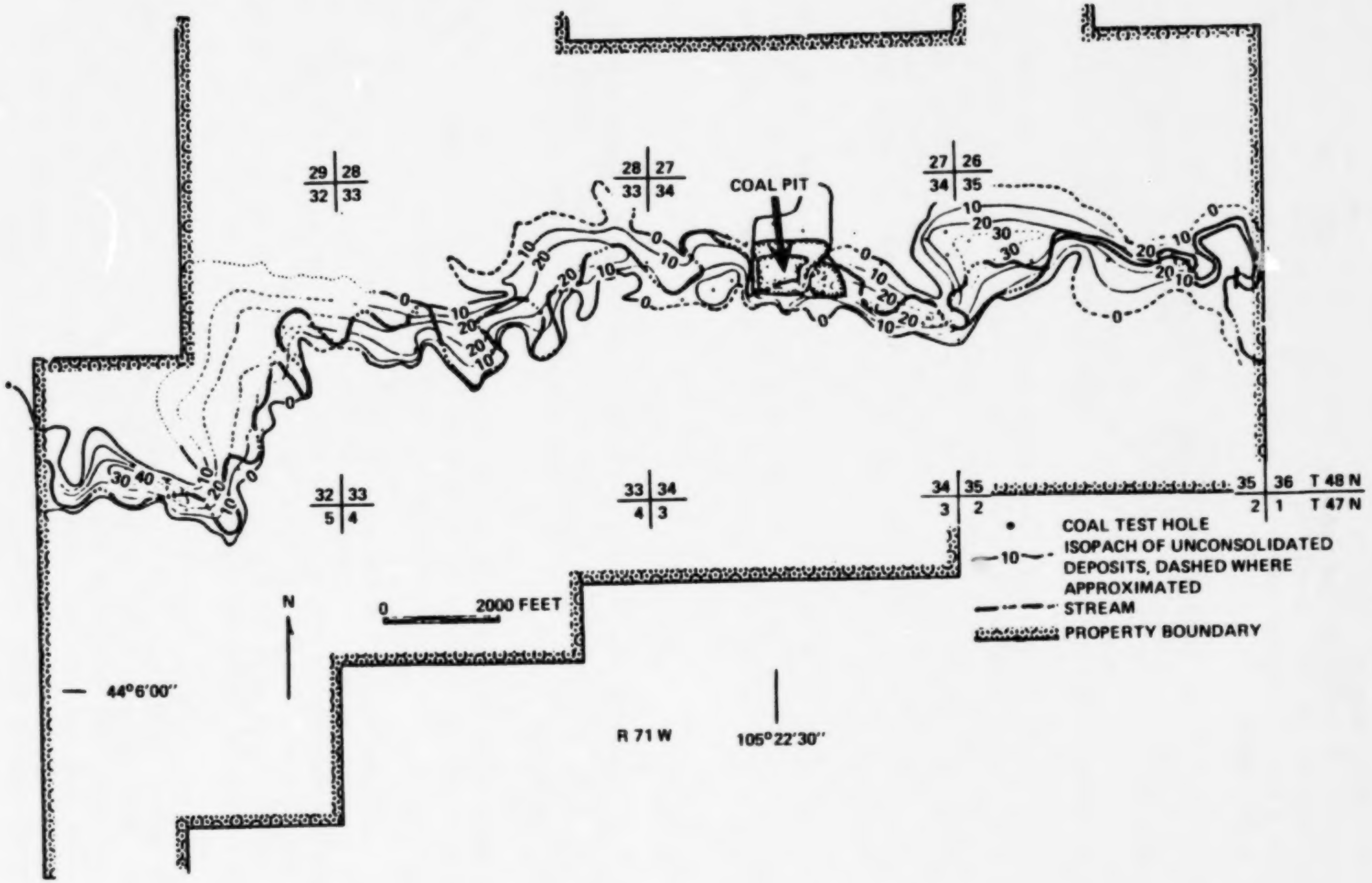

29 28
32 33
28 27
33 34
COAL PIT
27 26
34 35
32 33
5 4
33 34
4 3
34 35
3 2
35 36 T 48 N
2 1 T 47 N
0
10
20
30
40
COAL TEST HOLE
ISOPACH OF UNCONSOLIDATED DEPOSITS, DASHED WHERE APPROXIMATED
STREAM
PROPERTY BOUNDARY
N
0 2000 FEET
44°6'00"
R 71 W
105°22'30"

Figure 5-14. Isopach map of unconsolidated deposits along Caballo Creek (AMAX Coal Co., 1977).

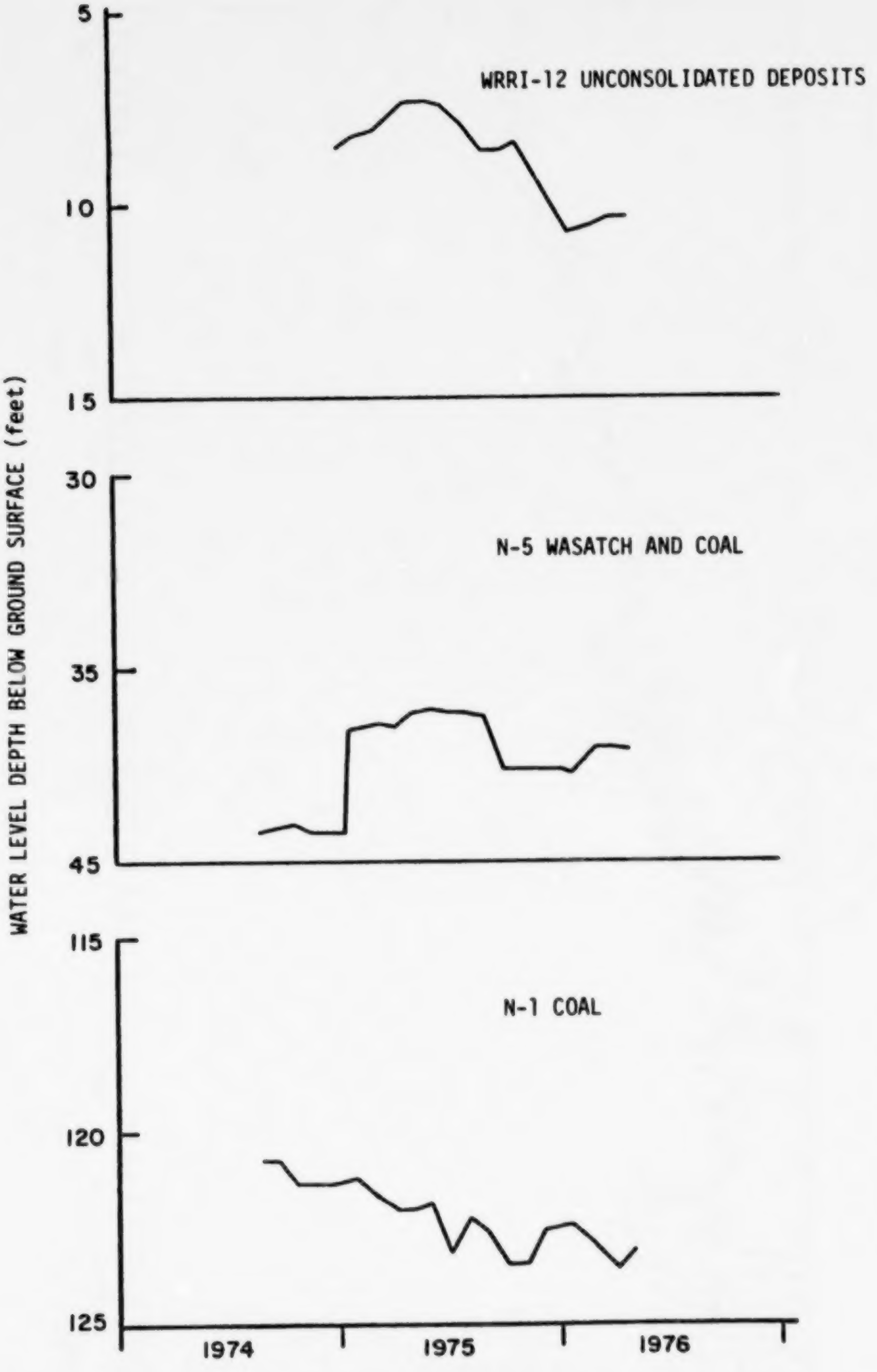


Figure 5-15. Hydrographs of three wells (AMAX Coal Co., 1977).

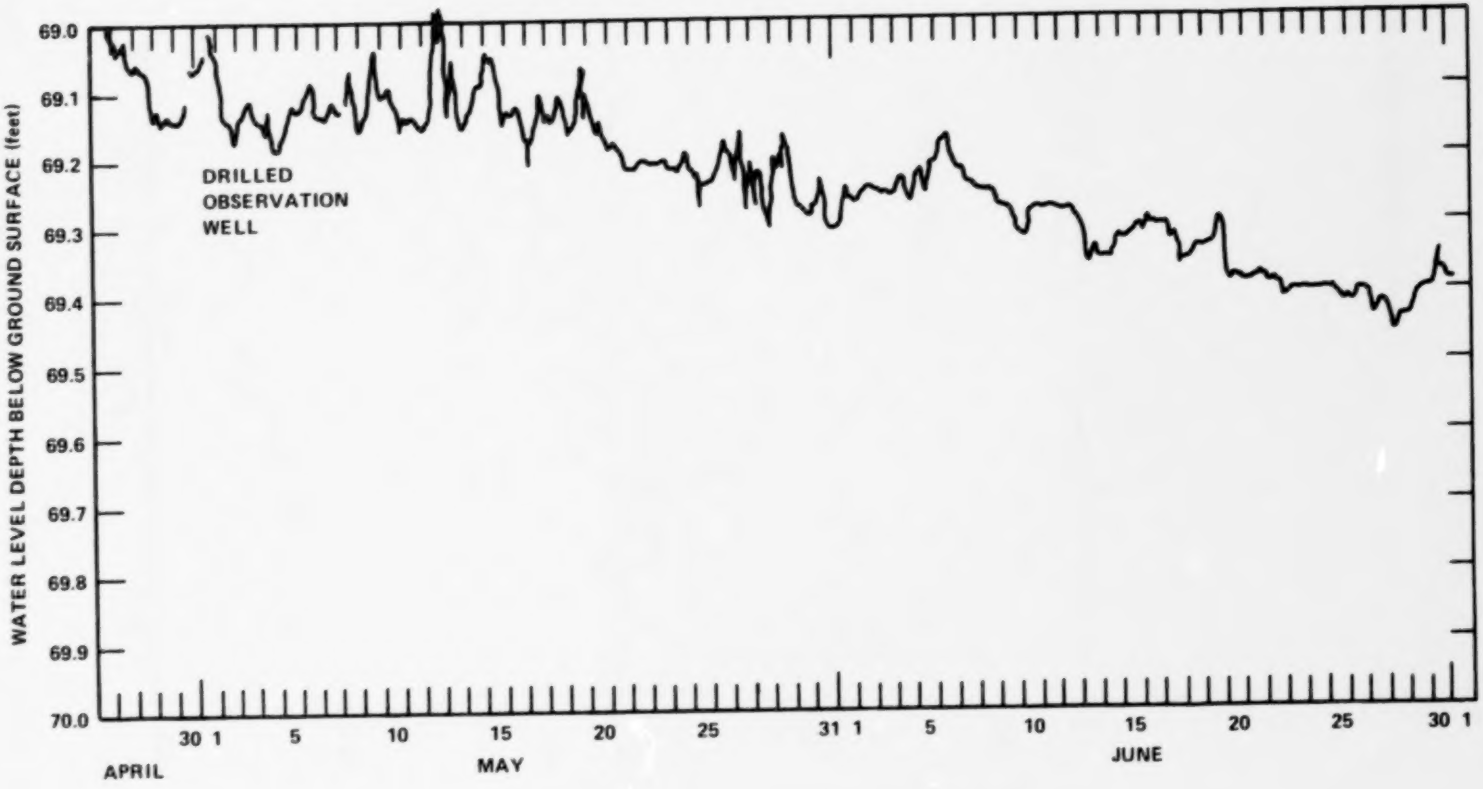


Figure 5-16. Water level fluctuations in well N-3, April 26 - July 1, 1974 (AMAX Coal Co., 1977).

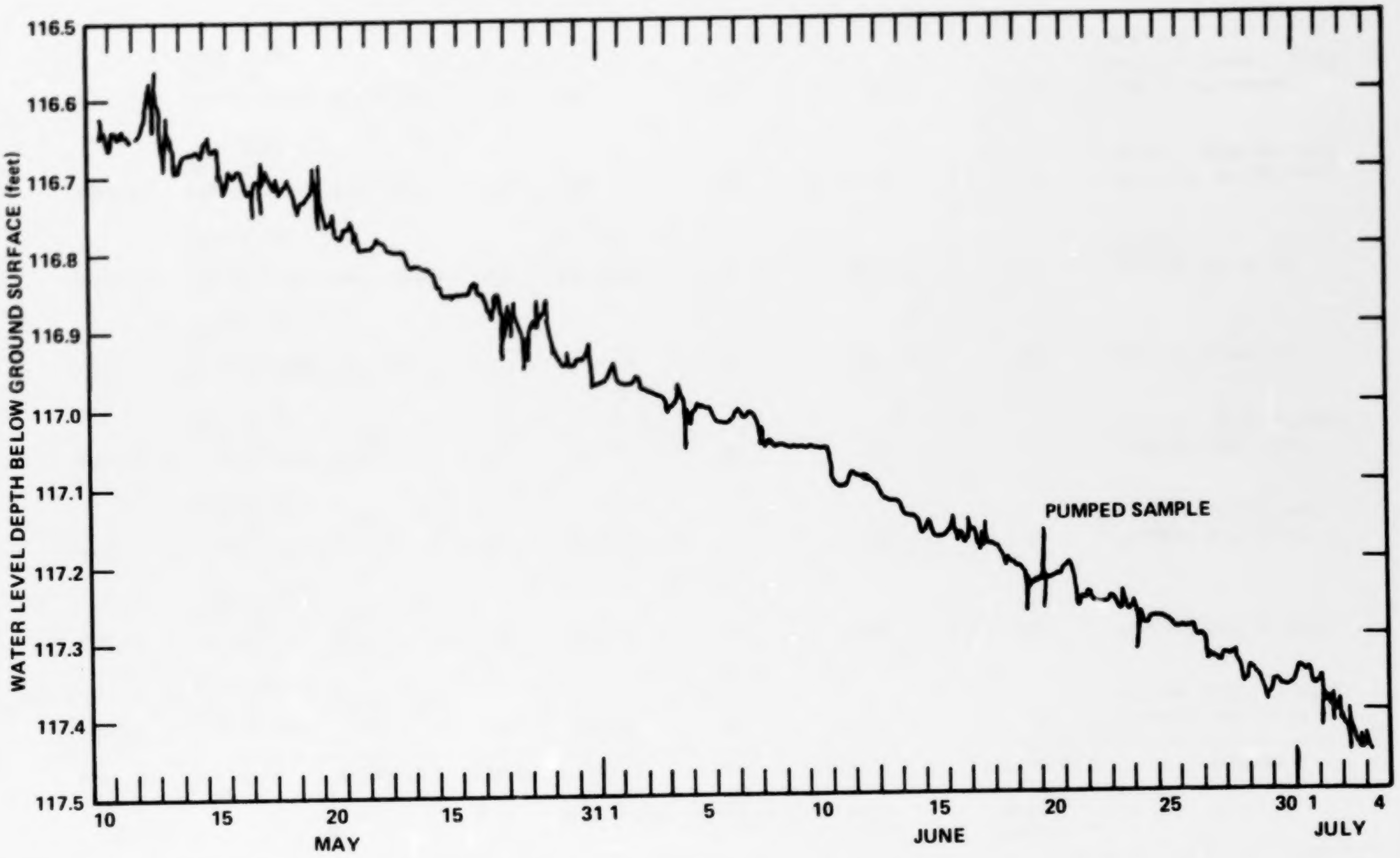


Figure 5-17. Water level fluctuations in well 481, May 10 - July 4, 1974 (AMAX Coal Co., 1977).

TABLE 5-7. WELL COMPLETION DATA, WRRI GROUNDWATER OBSERVATION WELLS, AMAX BELLE AYR SOUTH (AMAX Coal Co., 1977)

Well No.	Location	Formation	Total depth (feet)	Perforated depths (feet)	Depth to coal (feet)	Initial water level (ft.bl.g.s.)	Present water level (ft.bl.g.s.)	Remarks
WRRI-2	SE¼,SE¼,NW¼ Sec. 35 T48N,R71W	Cast overburden	36	30-36	NA	30	18	Located ≃60' N of stream south of mine
WRRI-3	NW¼,NW¼,SE¼ Sec. 27 T48N,R71W	Wyodak seam	206	166-206	166	186	NA	Plugged off at 122'
WRRI-5	SE¼,NE¼SE¼ Sec. 34 T48N,R71W	Wyodak seam	135	75-135	70	76	NA	Plugged off at 70' with bentonite mud
WRRI-5-A	SE¼,NE¼,SW¼ Sec. 34 T48N,R71W	Wyodak seam	135	75-35	70	76	76	Located ≃20' S of WRRI-5, SEAM project
WRRI-7	NW¼,SW¼,SW¼ Sec. 27 T48N,R71W	Fort Union	329	257-329	170	245	108	Coal is cased off.
WRRI-7-A	NW¼,SW¼,SW¼ Sec. 27 T48N,R71W	Fort Union	329	257-329	170	245	107	Located 35' W of WRRI-7
WRRI-8	SW¼,NE¼,NE¼ Sec. 33 T48N,R71W	Alluvium	20	NA	NA	9	9	75' N of bridge abutments. SEAM project
WRRI-9	SW¼,NE¼,NE¼ Sec. 35 T48N,R71W	Alluvium	18	NA	NA	9	9	≃20' E of ponded Caballo Creek. SEAM project

(continued)

TABLE 5-7 (continued)

Well No.	Location	Formation	Total depth (feet)	Perforated depths (feet)	Depth to coal (feet)	Initial water level (ft.bl.g.s.)	Present water level (ft.bl.g.s.)	Remarks
WRRI-10	NE¼,NE¼,SW¼ Sec. 31 T48N,R71W	Wyodak seam	281	188-281	188	30.2	30.2	Located 47' N of WRRI-12
WRRI-10-A	NE¼,NE¼,SW¼ Sec. 31 T48N,R71W	Wyodak seam	281	200-281	188	30.2	30.2	Located 47' N of WRRI-12
WRRI-11	NE¼,NE¼,SW¼ Sec. 31 T48N,R71W	Wasatch	194	90-124 174-194	NA	6.8	6.8	Located 66' N of WRRI-10
WRRI-12	NE¼,NE¼,SW¼ Sec. 31 T48N,R71W	Alluvium	20	0-20	NA	9	9	Located 60' NW of streamgage. SEAM project
N-1	SW¼,NE¼,SW¼ Sec. 27 T48N,R71W	Wyodak seam	190	130-190	130	168	119	Core hole that was reamed out and cased
N-3	SW¼,NW¼,NW¼ Sec. 3 T47N,R71W	Wyodak seam	122	50-122	44	85	69	Core hole
N-3-A	SW¼,NW¼,NW¼ Sec. 3 T47N,R71W	Wyodak seam	110	50-110	46	85	69	Located 38' of N-3
N-5-A	SE¼,SE¼SE¼ Sec. 28 T48N,R71W	Wasatch	135	40-135	NA	40	41	Offset of core hole

(continued)

TABLE 5-7 (continued)

Well No.	Location	Formation	Total depth (feet)	Perforated depths (feet)	Depth to coal (feet)	Initial water level (ft.bl.g.s.)	Present water level (ft.bl.g.s.)	Remarks
N-5-B	SE¼,SE¼,SE¼ Sec. 28 T48N,R71W	Wasatch	135	40-135	NA	40	41	Located 50' W of N-5-A
N-6	SE¼,SE¼,SE¼ Sec. 33 T48N,R71W	Wyodak seam	140	75-140	70	93	37	Core hole. SEAM project
N-11	SW¼,NW¼,NW¼ Sec. 28 T48N,R71W	Wasatch	207	140-200	207	NA	85	Offset of core hole. SEAM project
N-13	SE¼,SW¼,SE¼ Sec. 29 T48N,R71W	Wasatch	190	80-170	190	NA	60.5	Offset of core hole. SEAM project
N-13-A	SE¼,SW¼,SE¼ Sec. 29 T48N,R71W	Wasatch	190	80-170	190	NA	60	Located 28.5' N of N-1. SEAM project
481	SW¼,SE¼,SE¼ Sec. 27 T48N,R71W	Wyodak seam	160	100-160	95	110	118	Core hole

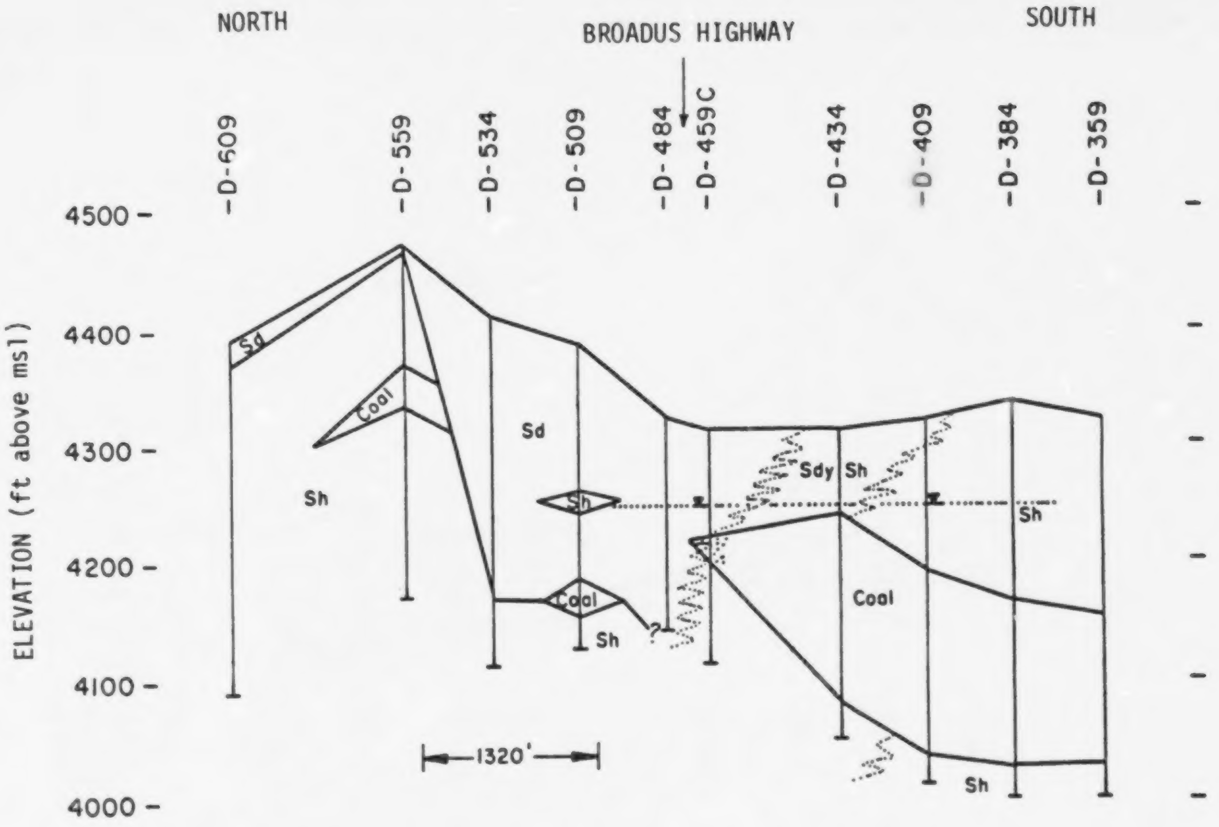

NORTH
BROADUS HIGHWAY
SOUTH
-D-609
-D-559
-D-534
-D-509
-D-484
-D-459C
-D-434
-D-409
-D-384
-D-359
4500
4400
4300
4200
4100
4000
ELEVATION (ft above msl)
Sd
Coal
Sh
Sd
Sh
Coal
Sh
?
Sdy
Sh
Sh
Coal
Sh
1320'

Figure 5-18. Geologic cross section from the center of the east line, section 22, to the NE corner, SE¼, NE¼, section 27, T51N, R72W. Well numbers are indicated across top. Dotted unit in hole D-459C is same scoria encountered in nearby well GN-8. Static water level is marked by dotted line between inverted triangles (AMAX Coal Co., 1977a).

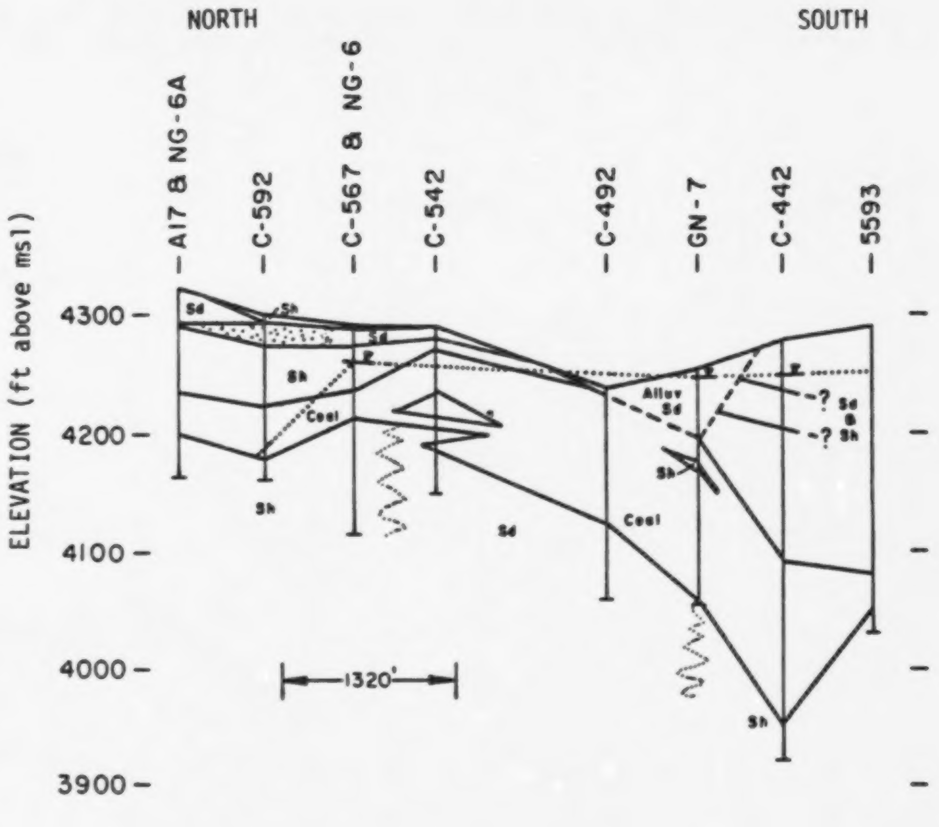

NORTH
SOUTH
A17 & NG-6A
C-592
C-567 & NG-6
C-542
C-492
GN-7
C-442
5593
ELEVATION (ft above msl)
4300
4200
4100
4000
3900
Sd
Sh
Sd
Sh
Coal
Sh
Sd
Alluv Sd
? Sd & ? Sh
Sh
Coal
Sh
1320'

Figure 5-19. Geologic cross section along west side of section 21, T51N, R72W. Well numbers are indicated across top. Scoria unit is dotted. Static water level is indicated by dotted line between inverted triangles (AMAX Coal Co., 1977a).

TABLE 5-8. SUMMARY OF AQUIFER TEST DATA (AMAX Coal Co., 1977a)

Test well No.	Date of test	Type test	Observ. well No.	Length of test (hrs.)	Prod. rate (gpm)	Final draw-down (ft)	Spec. cap. (gpm/ft)	Geol. fm.	Trans. (gpd/ft)	Aquif. Thick. (ft)	Perm. (gpd/ft^2)	Storage coeff.	Comments
BAN-1A	12-23-75	Sp. Cap.	–	3.42	0.63	27.0	0.02	Was.	30	30	1	–	
	12-12-75	Pump	BAN-1	3.42	–	0.50	–	Was.	177	30	5.9	0.003	r = 55'; Bound. Effects
BAN-3	8-18-75	Sp. Cap.	–	0.50	7.5	28.9	0.26	Coal	240	101	2.4	–	
BAN-4	8-18-75	Sp. Cap.	–	0.88	7.2	57.9	0.12	Coal	130	100 ?	1.3	–	
BAN-5	8-18-75	Sp. Cap.	–	0.82	3.5	3.2	1.1	Coal	1200	100 ?	12	–	
GN-6	23-28-75	Sp. Cap.	–	0.35	0.8	29.2	0.027	Coal	20	33	0.61	–	
GN-7	1-6-76	Sp. Cap	–	4.63	2.1	11.1	0.19	Coal	300	140	2.1	–	
	1-6-76	Pump	GN-7B	4.63	–	0.27	–	Coal	676	140	4.8	0.0011	r = 124'; Leaky Aquifer
GN-8	1-7-76	Sp. Cap.	–	0.78	13	0.1	130	Coal & Burn	140,000	58	2400	–	
GN-9	1-7-76	Sp. Cap.	–	0.33	0.05	30	0.002	FU	5	40	0.125	–	Pumped by air jet
D-305	6-27-74	Sp. Cap.	–	10.25	1.6	–	–	–	–	113	–	–	
	6-27-74	Pump	D-305A	10.25	–	0.56	–	–	1280	113	11	0.0022	r = 38.5

The major occurrence of alluvium on the lease is in the channel of Little Rawhide Creek. The streambed alluvium trends north through the lease area. There is also some alluvium in the Dry Fork Little Powder River streambed at the extreme southeastern corner of the Eagle Butte mine. The thickness of the alluvium is probably not greater than 40 feet at any point on the lease (AMAX Coal Co., 1977a). No pump test data have been published by AMAX for the alluvial areas.

The coal seams on the Eagle Butte lease yield water to wells. The coal thins towards the north (Figures 5-18 and 5-19) and is generally 75 feet thick throughout the lease area. Permeability in the coal is secondary in that all water flows through fractures. AMAX has not indicated that fracture orientation or developments have been studied. Hydraulic characteristics include transmissivities ranging from 20 to 1,200 gpd/ft (Table 5-8), and semiconfined storage coefficients (0.0011).

The water levels in all formations on the Eagle Butte lease are relatively stable. Annual fluctuations are generally less than 3 feet, as shown by Table 5-9. The well hydrographs (Figures 5-20 and 5-21) show that seasonal variations are slight, and that premining water levels are fairly stable.

The potentiometric surface in the Roland coal is continuous with the surface shown at the North Rawhide Mine. A groundwater mound exists at the west central edge of the lease, indicating a possible recharge area or poorly confined conditions. The primary direction of groundwater flow on the lease is northwest.

AMAX has published data on 30 monitor wells being used on the Eagle Butte property. Completion information can be found in Table 5-10. The well locations are also given in the table.

ARCO Black Thunder —

Fairly extensive groundwater investigations have been conducted on the Black Thunder lease by Atlantic Richfield and by the University of Wyoming. These researchers have paid considerable attention to the Roland coal aquifer, Wasatch aquifers, and pre-Roland aquifers. Scoria and alluvial aquifers are relatively unstudied.

Wasatch aquifers on the lease are local phenomena. Lenticular sandstones transmit small amounts of water (usually less than 15 gpm) to wells. No pump tests have been run on Wasatch wells. The Wasatch overburden thickens from east to west on the mine site, and where groundwater does exist, such waters are unconfined.

Scoria units exist to the east of ARCO's proposed mine. For this reason, minimal study of these clinker units has occurred. ARCO notes that such scoria beds have high permeabilities, with water transmitting capabilities similar to those of gravels. Alluvium exists in the valleys of Little Thunder and North Prong Creeks. The alluvium has not been studied to any extent, but ARCO indicates that lithologies include unconsolidated gravels, sands, and clays.

TABLE 5-9. STATIC WATER LEVELS MEASURED ON UNINSTRUMENTED WELLS (AMAX Coal Co., 1977a)

	Static water levels (ft below casing top)														
Well No.	8/18/75	12/4/75	12/18/75 to 1/7/76	1/10/76	2/13/76	3/2/76	3/31/76	5/5/76	6/15/76	7/2/76	8/1/76	9/1/76	10/13/76	11/1/76	12/2/76
BAN-3	74.6	75.0	(Casing cut 1.5')	-	-	74.5	78.8	73.6	74.0	74.3	-	-	-	-	75.8
BAN-4	37.1	29.0	-	-	-	28.9	28.7	28.3	20.6	28.6	-	29.3	29.8	-	29.9
BAN-5	79.2	79.0	-	-	-	78.9	-	80.0	78.9	79.1	-	79.2	79.0	-	79.1
GN-6A	-	-	Dry hole – not cased		-	-	-	-	19.8	-	20.1	-	-	-	-
GN-6B	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
GN-6	-	-	25.8	-	-	26.7	26.4	26.6	26.4	25.8	-	24.8	25.0	-	25.5
GN-7	-	-	7.0	-	-	6.5	6.1	-	6.7	6.9	-	7.6	7.5	-	7.2
GN-7A	-	-	10.1	-	-	-	7.0	-	7.0	7.3	-	7.9	8.1	-	7.8
GN-7B	-	-	6.9	-	-	6.8	6.7	-	7.0	7.3	-	5.8	7.6	-	7.2
GN-7(OB)	-	-	7.3	-	-	7.3	-	-	-	-	-	-	-	-	-
GN-8	-	-	63.4	-	-	77.9	63.9	-	63.5	63.5	-	64.9	64.4	-	63.5
GN-9	-	-	72.3	-	-	68.2	63.3	60.1	-	57.0	-	54.6	54.1	-	56.6
GN-9A	-	-	11.3	-	-	9.9	9.9	9.9	-	10.0	-	9.7	9.5	-	-
GN-9(C)	-	-	28.0	-	-	-	-	-	-	-	-	-	-	-	-
GNH-1	8.1	-	-	9.5	-	7.6	6.7	6.2	6.0	6.2	-	8.6	9.1	-	6.7
GNH-3	6.6	-	-	8.6	-	4.9	4.3	2.1	3.9	4.5	-	7.5	6.5	-	4.1
GNH-4	13.4	-	-	15.4	-	11.6	9.8	9.9	7.4	9.7	-	Casing broken		-	-
GNH-5	11.6	-	-	13.3	-	11.3	9.7	10.5	11.0	-	-	12.5	12.4	-	13.8
GNH-6	9.0	-	-	9.7	-	6.5	6.6	6.4	7.9	-	-	9.4	9.8	-	13.2
GNH-10	8.3	-	-	8.9	-	8.5	11.9	8.0	7.9	8.2	-	8.9	9.0	-	12.5
GNY-11	-	-	-	9.7	-	10.7	10.5	9.4	Casing broken		-	-	10.0	-	-
GNH-12	2.9	-	-	4.1	-	4.1	3.9	3.5	3.4	4.9	-	Plugged	-	-	-
D305A	-	-	-	-	79.0	-	-	-	77.5	78.6	-	-	-	-	-
AMAX #8	-	-	-	-	-	13.1	20 ?	-	-	-	-	-	-	-	-

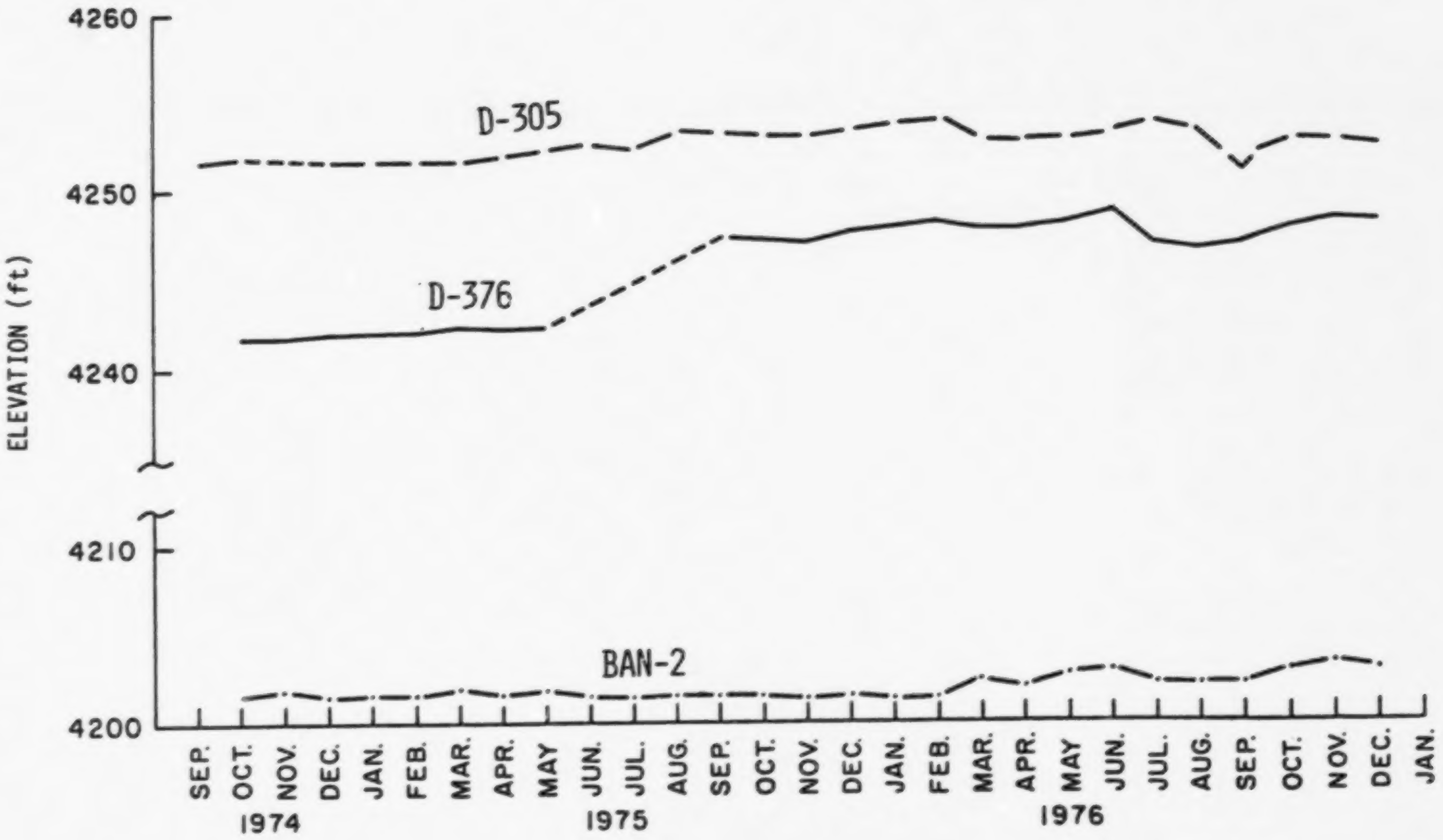


Figure 5-20. Monthly water level elevations in instrumented monitor wells. The rise in water level in D-376 during summer and fall of 1975 is probably due to a change in monitoring personnel (AMAX Coal Co., 1977a).

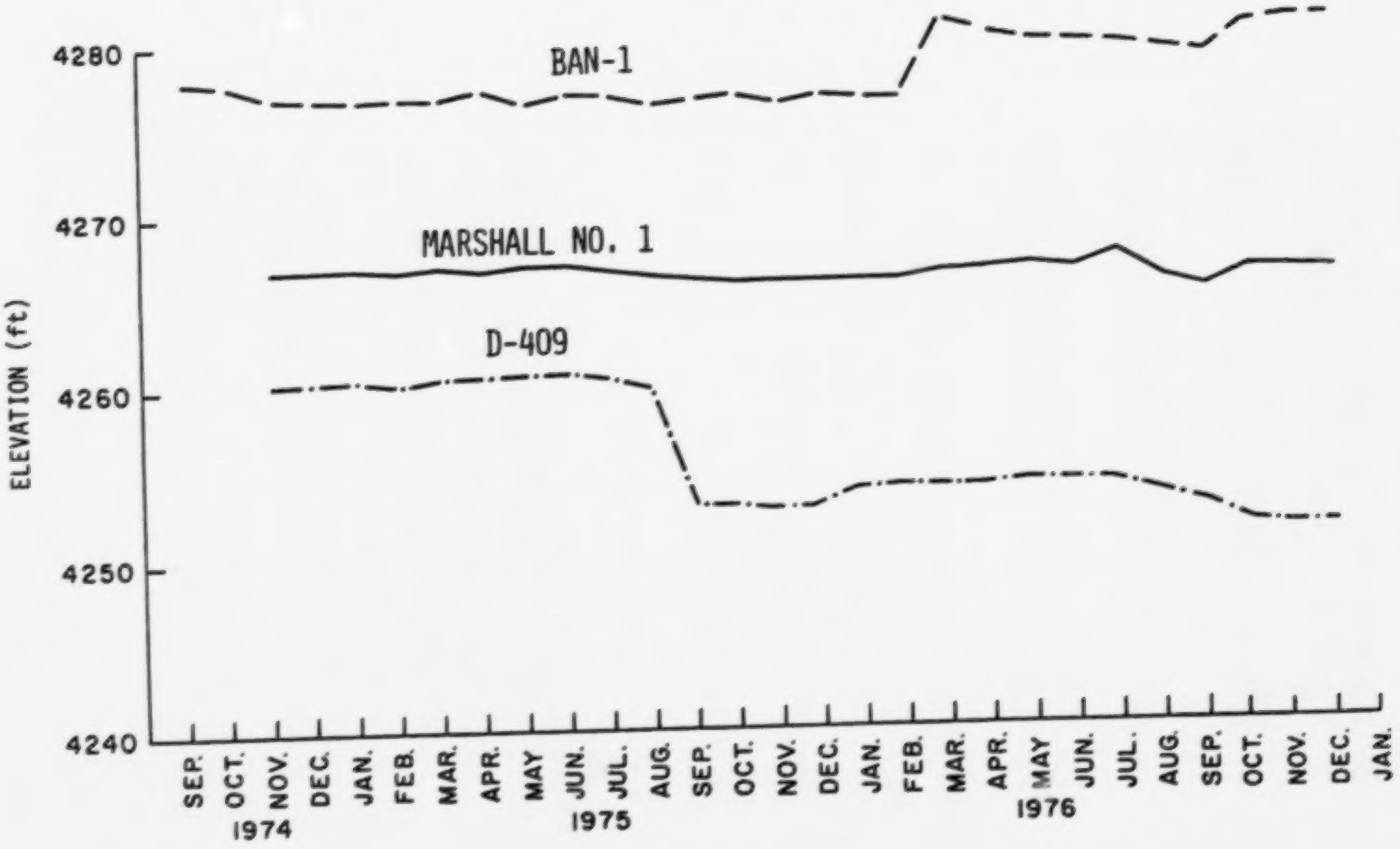


Figure 5-21. Monthly water level elevations in instrumented monitor wells. The sharp drops in water levels in D-409 during fall 1975 are probably due to a change in monitoring personnel (AMAX Coal Co., 1977a).

TABLE 5-10. MONITOR WELL INVENTORY FOR AMAX'S EAGLE BUTTE MINE. ELEVATION SOURCES ARE LEVELINE SURVEY (S), TOPOGRAPHIC MAPS (T), AND COMBINATIONS OF THE TWO (Tc) (AMAX Coal Co., 1977a)

	Location				Elevation										
Well No.	Coordinates (ft)	Sec	T	R	Ground (ft,msl)	Source	Casing height (ft)	Total depth (ft)	Casing depth (ft)	Cement or packer depth (ft)	Perf. interval (ft,depth)	Formation	Logs (X=same hole)	Casing desc.	Date drilled
BAN-1	1720 fel, 150 fnd	22	51N	72W	4349	S	0.7	210	0-195	Surf.	95-195	[a]Was.	D482	4" PVC	6-18-74
BAN-1A	1670 fel, 160 fnd	22	51N	72W	4345	S	1.5	218	0-218	Surf.	118-218	Was.	D482,X	4" PVC	6-20-74
BAN-2	2000 fnl, 2050 fel	26	51N	72W	4336	T	1.0	390	0-240	240	Open hole	Coal	D339,X	4" PVC	6-21-74
BAN-3	728 fnl, 2160 fel	16	51N	72W	4227.8	S	1.6	224	0-224	82	164-244	Coal	X	4" PVC	9-75
BAN-4	2770 fnl, 1880 fwl	16	51N	72W	4202.8	S	2.1	173	0-173	54	123-173	Coal	X	4" PVC	9-75
BAN-5	1775 fnl, 20 fwl	16	51N	72W	4276.8	S	0.8	160	0-160	123	125-160	Coal	H167	4" PVC	9-75
GN-6	1290 fnl, 20 fwl	21	51N	72W	4290.6	T	3.0	76	0-76	42	42-75	Coal	X	5" PVC	12-75
GN-6A	20 fnl, 20 fwl	21	51N	72W	–	–	0.0	117	None	–	–	–	X	None	12-75
GN-7	1280 fsl, 60 fwl	21	51N	72W	4252.5	S	1.4	260	0-260	76	180-260	Coal	X	5" PVC	12-75
GN-7(OB)	1280 fsl, 60 fwl	21	51N	72W	4252.5	S	1.3	74	0-74	–	54-74	[b]Qal.	GN-7	1" Stl	12-75
GN-7A	1460 fsl, 60 fwl	21	51N	72W	4252.2	S	0.6	260	0-26	76	18-260	Coal	GN-7	5" PVC	12-75
GN-7B	1660 fsl, 60 fwl	21	51N	72W	4252.1	S	1.3	157	0-20	–	0-20	Qal.	GN-7	5" PVC	12-75
GN-8	1620 fsl, 20 fwl	23	51N	72W	4312.9	S	1.4	117	0-117	60	60-307	Coal&Burn	D459C	5" PVC	12-75
BN-9	1620 fsl, 770 fel	28	51N	72W	4279.3	S	2.0	313	0-307	263	307-267	[c]FU	X	5" PVC	12-75
GN-9(C)	1620.fsl, 770 fel	28	51N	72W	4279.3	S	2.2	261	0-183	None	163-183	Coal	GN-9	1" Stl	12-75
GN-9A	1620 fsl, 830 fel	28	51N	72W	4277	T	2.1	320	0-107	57	67-107	Was.	GN-9	5" PVC	12-75
D-305	2620 fsl, 2210 fel	27	51N	72W	4330.3	S	1.5	356	0-240	240	240-356	Coal & FU	GN-9,X	5" PVC	6-22-74
D-305A	2581 fsl, 2210 fel	27	51N	72W	4328.8	S	1.4	365	0-240	240	240-365	Coal & FU	D-305	5" PVC	6-24-74
D-376	680 fnl, 00 fwl		51N	72W	4291.4	S	0.7	330	0-158	158	158-330	Coal	X	5" PVC	6-25-74
D-409A	Swenr	23	51N	72W	4319.5	S	0.4	330	0-155	155	155-330	Coal & FU	X	5" PVC	6-21-74
GNH-1	520 fsl, 2650 fwl	16	51N	72W	4200.2	S	0.8	17	17	None	14-17	Qal.	X	1¼" Stl	9-75
GNH-3	160 fsl, 2230 fwl	16	51N	72W	4202.7	S	1.0	13	12	None	9-12	Qal.	X	1¼" Stl	9-75
GNH-4	810 fsl, 3020 fwl	16	51N	72W	4197.7	S	3.5	15	14	None	11-14	Qal.	X	1¼" Stl	9-75
GNH-5	2340 fsl, 2820 fwl	16	51N	72W	4187.9	S	1.1	17	15	None	12-15	Qal.	X	1¼" Stl	9-75
GNH-6	2540 fsl, 3530 fwl	16	51N	72W	4182.2	S	3.2	31	14	None	11-14	Qal.	X	1¼" Stl	9-75
GNH-10	2830 fsl, 2910 fwl	16	51N	72W	4182.81	S	1.1	18	12	None	9-12	Qal.	X	1¼" Stl	9-75
GNH-11	1640 fsl, 2890 fwl	16	51N	72W	4191.9	S	3.5	15	11	None	8-11	Qal.	X	1¼" Stl	9-75
GNH-12	3120 fsl, 2890 fwl	16	51N	72W	4177.0	S	1.7	15	11½	–	8½-11½	Qal.	X	1¼" Stl	9-75
Marshall #1	2730 fsl, 70 fwl	27	51N	72W	4283.4	T	0.0	–	–	–	–	–	5070	4" PVC	1973(?)
AMAX #8	NW, NW, NW, NE	28	51N	72W	4275	T	1.9	58	58	30	30-58	Coal	C421	5" PVC	1-76

[a] Wasatch
[b] Quaternary Alluvium
[c] Fort Union

The pre-Roland aquifer is composed of fractured shales and other fine-grained materials. These materials have low permeabilities, but they are saturated. The University of Wyoming study indicates that the pre-Roland aquifer is confined, but the nature and/or location of the confining layer is unclear. It is assumed that the strata directly beneath the Roland seam must act as the confining layer. The University of Wyoming study indicates that some upward leakage may occur through this confining layer. As shown by Table 5-11, one pump test in the pre-Roland material did not yield interpretable data. A second pump test did give a transmissivity value of 7,200 gpd/ft, indicating that the pre-Roland material may be as permeable or more so than the Roland coal itself.

The Roland coal has been pump tested many times as indicated by Table 5-11. Transmissivity values ranged from 32 to 25,000 gpd/ft, with an average value of 35,000 gpd/ft, and storage coefficients generally reflected confined conditions or semiconfined conditions. ARCO has indicated in its Mining Plan Update (1977) that the coal is virtually full of water except for some areas in the eastern part of the lease. In these areas, water table or semiconfined conditions are expected. The Roland seam is approximately 70 feet thick over the lease area.

The potentiometric surface map submitted by ARCO in its 1977 Mining Plan Update shows levels monitored in 1974 (Figure 5-22). Groundwater flow in the Roland aquifer generally had a westward component, as supported by carbon-14 age information submitted by the University of Wyoming (Figure 5-23). ARCO has increased its number of monitoring wells since 1974 and, hopefully, is studying interaquifer exchanges and potentiometric surface changes. Figure 5-24 shows monitor well locations.

Carter North Rawhide—

The groundwater systems beneath Carter's Rawhide Mine lease are described in the company's May 1977 Mining Plan Update. Groundwater exists in the Wasatch Formation, the scoria hills, the alluvium, the coal seams, and above and below the coal seams as indicated by Table 5-12.

Approximately 50 percent of the Wasatch overburden is composed of sandstones. These sandstones are interbedded with the clays, shales, and siltstones which comprise the remainder of the Wasatch Formation. The discontinuous character of and the questionable hydraulic connections between the sandstone units limit their performance as prolific water-bearing systems. The Wasatch aquifers generally have an unconfined potentiometric surface, although local shales or clays may confine the water for short distances.

The scoria deposits at the Rawhide mine bear close inspection. In late 1976, a scoria hill was breached during construction excavation. Carter had to pump 6,000 gpm for several days to dewater the hill. Water levels were measured frequently throughout this dewatering, and the declines were analyzed to get an idea of the hydraulic properties of the scoria. Transmissivity values on the order of 10^6 gpd/ft were calculated. Not all clinker (scoria) deposits are saturated, however, and additional data are required to adequately assess scoria hydrogeology.

TABLE 5-11. CALCULATED VALUES OF TRANSMISSIVITY AND STORAGE COEFFICIENT IN ROLAND FORMATION (ARCO, 1977)

Pumped	Obser-vation	Aquifer	Test method	Obser-vation radious (ft)	Flow rate (gpm)	Average trans-missivity (gpd/ft)	Storage co-efficient	Comments
R1	–	Roland	Jacob[a]	–	6.8	4,600[b]	–	Data erratic; results questionable
R2	–	Roland	Jacob	–	21.4	5,600[b]	–	Data skewed
R2	R2A	Roland	Leaky aquifer	93	21.4	3,400	4.4×10^{-4}	Leaky condition
R5	–	Roland	Jacob	–	21.8	3,800[b]	–	–
R5	R-5A	Roland	Theis	93	21.8	5,600	2.5×10^{-4}	Slightly skewed data
R6	–	Roland	Jacob	–	15.0	100[c]	–	Data skewed; results questionable
R7	–	Roland	Jacob	–	20.0	3,800[b]	–	Data skewed at end
R8	–	Roland	Jacob	–	30.0	4,500[b]	–	Data erratic between drawdown and recovery
R9	–	Roland	Jacob	–	5.0	1,300[c]	–	Data erratic
R10A	–	Roland	Jacob	–	5.0	4,400[b]	–	Data skewed
R10A	R10D	Roland	Jacob	60	50.0	25,000[d]	7.0×10^{-3}	Data slightly skewed
R12	–	Roland	Jacob	–	5.0	450[b]	–	Data erratic
R12A	R12B	Roland	Jacob	24.5	5.0	750[d]	2.0×10^{-3}	Data reasonable
R12B	R12C	Roland	Theis	39.5	15.0	650	1.5×10^{-6}	Data did not fit curve well
PR12E	–	Pre-Roland	Data too erratic to analyze					
R17A	R17	Roland	Theis	100.0	12.0	300	6.0×10^{-4}	Data fit Theis better than leaky
R151	–	Roland	Jacob	–	23.2	600[b]	–	Data erratic
R153	–	Roland	Jacob	–	6.0	32[c]	–	Data skewed
R154	–	Roland	Jacob	–	4.0	32[b]	–	Data somewhat erratic
Silo #2	–	Pre Roland	Jacob	–	50.0	7,200[b]	–	Data skewed slightly
Stuart Ranch	–	–	Jacob	–	50.0	790	–	Data skewed

---

[a] Jacob method works well only in homogeneous and isotropic artesian aquifers with a small radius and a large time period (Walton, 1970). May be a reason for skewed and erratic test data and results.

[b] Average value between drawdown and recovery test analyses

[c] Recovery test only analyzed

[d] Drawdown test only analyzed

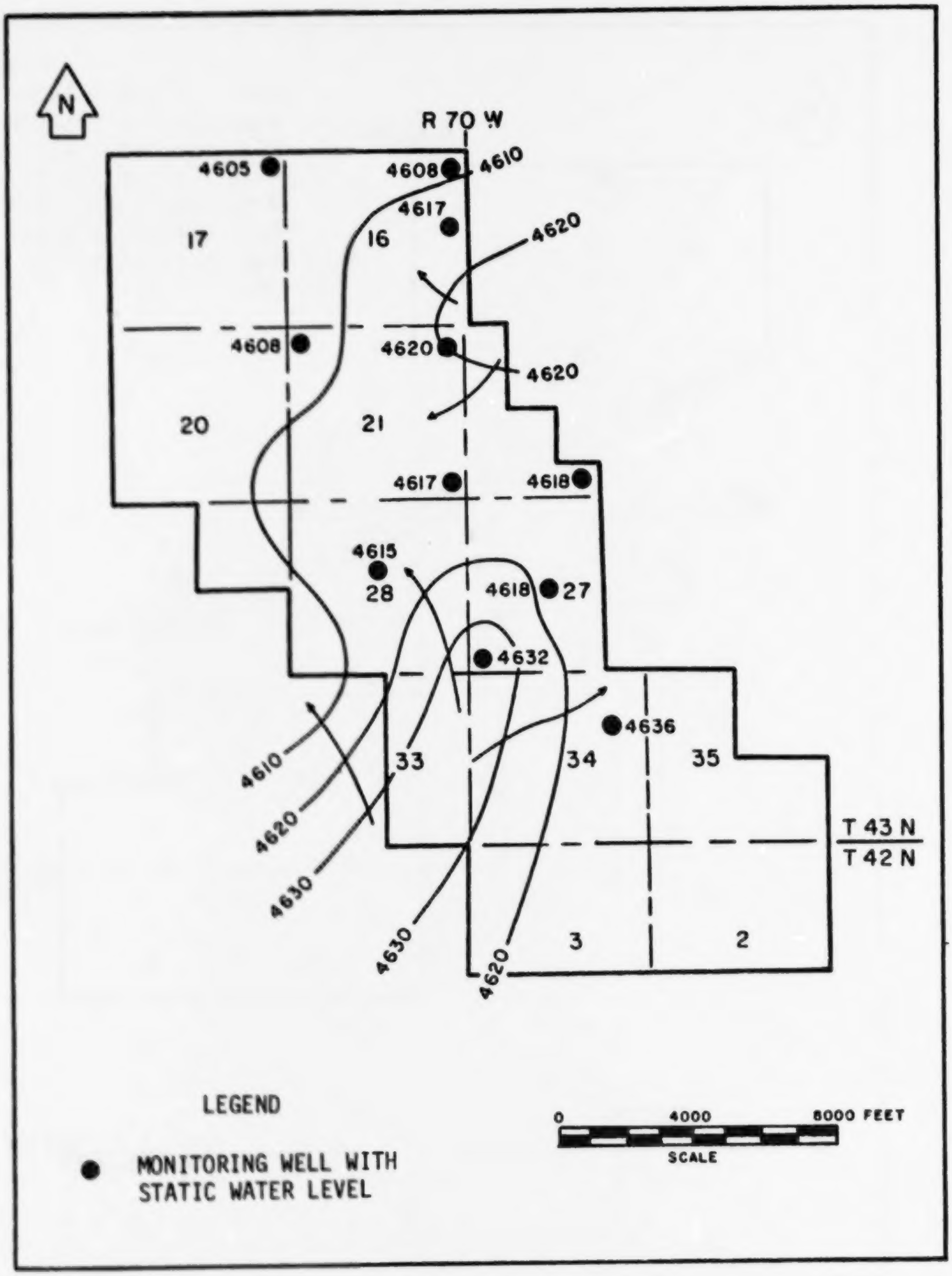

N
R 70 W
4605
4608
4610
4617
17
16
4620
4608
4620
4620
20
21
4617
4618
4615
28
4618
27
4632
4636
4610
33
34
35
4620
4630
T 43 N
T 42 N
4630
4620
3
2
LEGEND
● MONITORING WELL WITH STATIC WATER LEVEL
0
4000
8000 FEET
SCALE

Figure 5-22. Potentiometric surface map, ARCO Black Thunder Lease (ARCO, 1977).

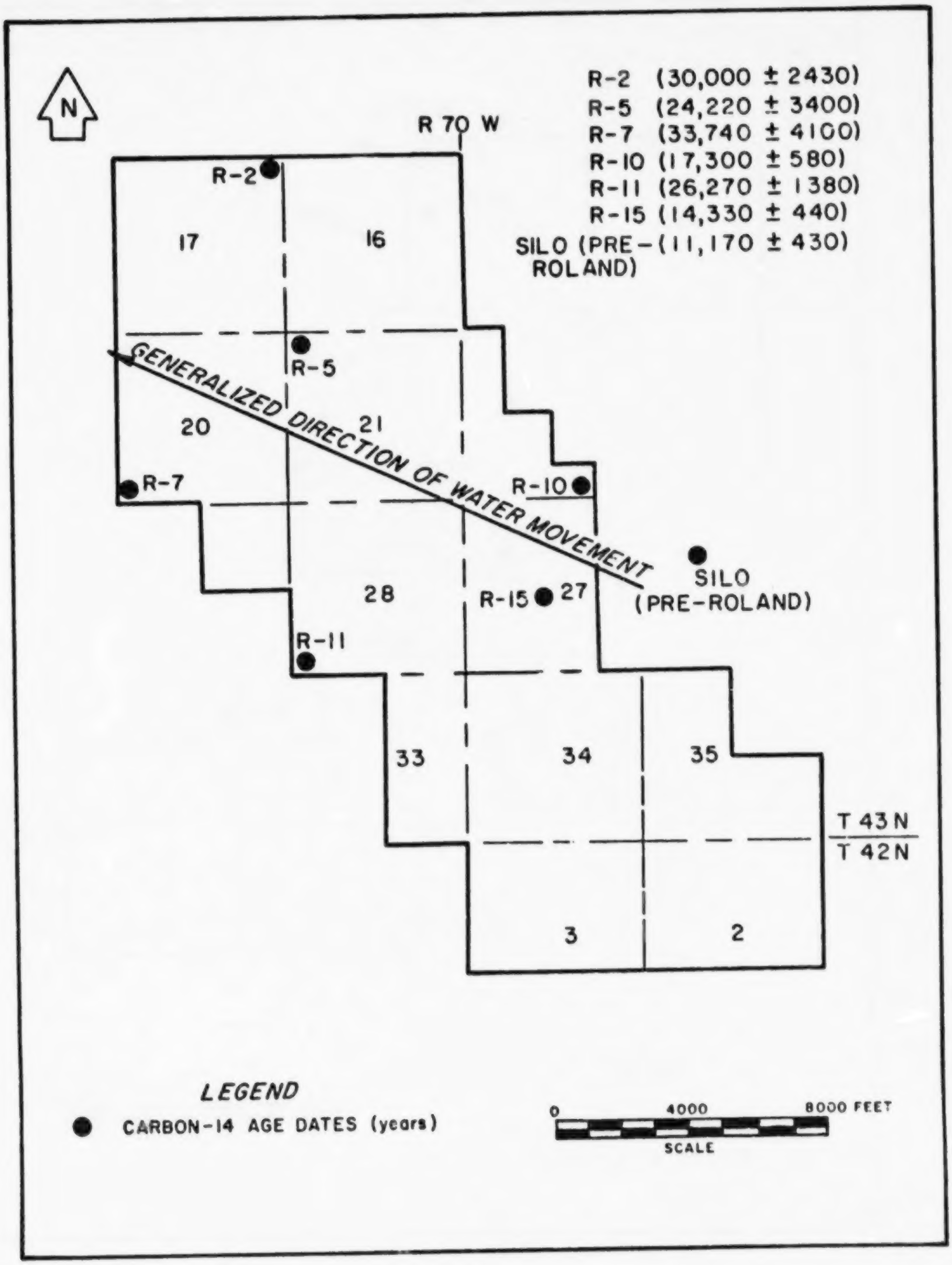

N
R 70 W
R-2 (30,000 ± 2430)
R-5 (24,220 ± 3400)
R-7 (33,740 ± 4100)
R-10 (17,300 ± 580)
R-11 (26,270 ± 1380)
R-15 (14,330 ± 440)
SILO (PRE-ROLAND) (11,170 ± 430)
R-2
17
16
R-5
20
21
GENERALIZED DIRECTION OF WATER MOVEMENT
R-7
R-10
28
R-15
27
SILO (PRE-ROLAND)
R-11
33
34
35
T 43 N
T 42 N
3
2
LEGEND
● CARBON-14 AGE DATES (years)
0
4000
8000 FEET
SCALE

Figure 5-23. Groundwater flow in Roland aquifer (University of Wyoming, 1976).

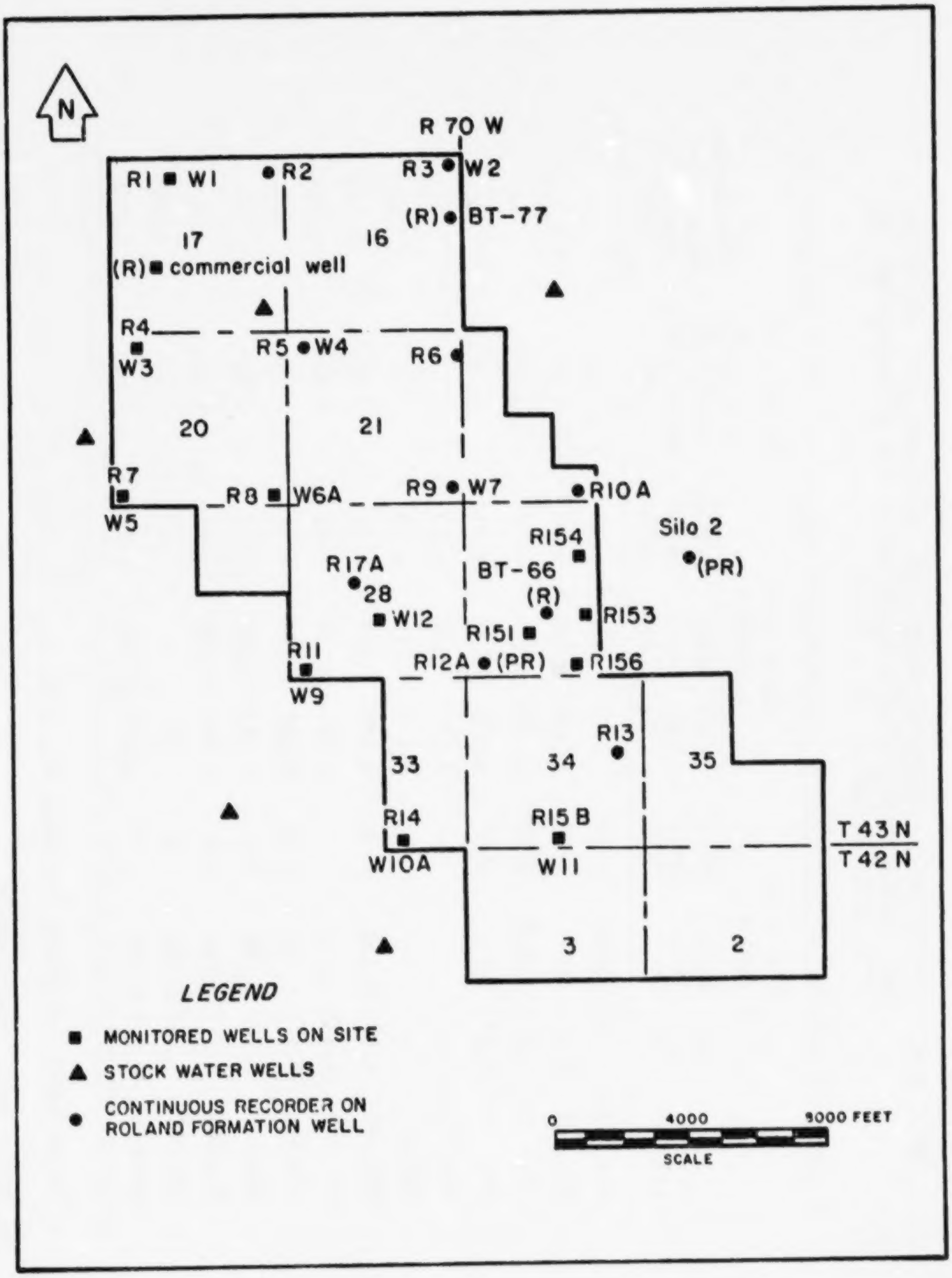

N
R 70 W
R1 W1
R2
R3 W2
(R) BT-77
17
16
(R) commercial well
R4
W3
R5 W4
R6
20
21
R7
W5
R8 W6A
R9 W7
R10A
Silo 2
(PR)
R154
R17A
28
BT-66
(R)
R153
W12
R151
R11
W9
R12A (PR)
R156
R13
33
34
35
R14
W10A
R15 B
W11
T 43 N
T 42 N
3
2
LEGEND
■ MONITORED WELLS ON SITE
▲ STOCK WATER WELLS
● CONTINUOUS RECORDER ON ROLAND FORMATION WELL
0
4000
8000 FEET
SCALE

Figure 5-24. Monitor well locations, ARCO Black Thunder Lease (University of Wyoming, 1976).

TABLE 5-12. SUMMARY OF ELEVATION OF WATER LEVEL IN ROLAND COAL, SMITH COAL, AND OVERBURDEN COMPARED TO ELEVATION OF TOP OF ROLAND COAL AND SMITH COAL (Carter Oil Co., 1977)

Well site	Roland coal elevation			Smith coal elevation			Roland coal (+) above (-) below Smith coal water level, (ft)	Overburden water level elevation, (ft)
	Coal top, (ft)	Water level, (ft)	Difference[a] (ft)	Coal top, (ft)	Water level, (ft)	Difference[a] (ft)		
NRH- 1	4,245	4,259	+ 14	–	–	–	–	–
NRH- 2	4,171	4,241	+ 70	4,140	4,164	+ 24	+ 77	4,244
NRH- 3	4,232	4,363[b]	+131[b]	4,195	4,187	- 8	+176[b]	–
NRH- 4	4,128	4,155	+ 27	4,095	4,146	+ 51	+ 9	–
NRH-239	–	–	–	4,274	4,197	- 77	–	–
NRH-241	–	–	–	4,131	4,113	- 18	–	–
NRH-242	4,172	4,180	+ 8	4,140	4,153	+ 13	+ 27	4,126
NRH-243	4,235	4,218	- 17	4,200	4,155	- 45	+ 63	4,244
NRH-244	4,111	4,123	+ 12	4,065	4,129	+ 64	- 6	–
NRH-245	4,090	4,155	+ 65	4,041	4,180	+139	- 25	–
NRH-246	4,017	4,150	+133	3,981	4,140	+159	+ 10	–
NRH-247	4,106	4,204	+ 98	–	–	–	–	4,198
NRH-268	4,256	4,248	- 7	4,223	4,203	- 20	+ 45	4,276

[a] Water level (+) above (-) below top of coal

[b] Water level questionable

Alluvial aquifers are an important part of the hydrogeologic conditions at the Rawhide mine. Composed of silt, sand, and gravel, these units are moderately permeable. Saturated thicknesses range from 20 feet at Rawhide Creek to 40 feet along Dry Fork Little Powder River (Carter Oil Co., 1977). The alluvial aquifer systems are 100 to 1,000 feet wide, and roughly follow the meandering courses of the streams.

The coal seams carry groundwater in their fractures. The development of the fractures determines the water-bearing characteristics of the coal aquifer. In its mining plan update, Carter Oil Co. (1977) published pump test information for only one well, #NRH-2, showing values of 115 gpd/ft for transmissivity in the Roland coal and of 310 gpd/ft for the Smith coal. Storage coefficients were 0.0002 and 0.003 for the Roland and Smith coals, respectively. These storage coefficients indicate confined conditions, although water level measurements show that the coal seams are not fully saturated in some areas. Storage coefficients in these unsaturated areas will be in the range from 0.001 to 0.10.

The Carter Oil Co. (1977) Plan Update notes that circulation patterns are complex and not very well understood. Relationships among all four aquifers will have to be studied and reported. Water well descriptions are contained in Table 5-13.

Kerr-McGee Jacobs Ranch—

The Jacobs Ranch mine is relatively dry when compared with mines in the northern part of the study area. Groundwater occurs primarily in the Wasatch overburden and in the coal seams. There is no significant alluvial area, and according to Kerr-McGee Coal Corp. (1977), no extensively saturated scoria regions have been encountered.

As shown on Figure 5-25, a scoria-coal contact exists on the eastern and southern sides of the lease. Field observations of cuts into the scoria found that the scoria was essentially dry. However, Kerr-McGee has not drilled extensively in the scoria, and the possibility of encountering saturated, highly permeable material should not be discounted. Indeed, as the pump test at well #2 indicates (Table 5-14), scoria in this area contributed water through coal fractures to establish relatively large transmissivity figures.

Figure 5-26 indicates that the coal seams at Jacobs Ranch dip to the west. Confined or semiconfined flow through fractures is probably westward. Aquifer thicknesses on the order of 70 feet yielded transmissivity values ranging from 50 to 400 gpd/ft. However, discharge was not adequately controlled, and these figures should be substantiated with additional data. Storage coefficients computed at observation wells are indicative of confined aquifer conditions.

Water levels in monitor wells on the Jacobs Ranch mine have remained relatively stable for 3 years (see Figures 5-27 and 5-28). As a potentiometric surface map for the mining plan update, Kerr-McGee submitted a summary of water levels from water rights adjudication data. No contours were drawn, and the completion depths of the wells were not consistent. Monitor well information at Jacobs Ranch is shown on Figure 5-29 and in Table 5-15.

TABLE 5-13. INVENTORY OF WELLS AND SPRINGS, RAWHIDE BLOCK NEAR GILLETTE, WYOMING (Carter Oil Co., 1977) (see pages 142, 143, and 144 for explanation of column headings and supplementary notes)

Well number (1)	Ranch or house identification (2)	Use (3)	Depth (feet) (4)	Year completed (5)	Type of power (6)	MP elev. (feet) (7)	Depth to water feet (8)	Depth to water date (9)	GPM (10)	Date (11)	Used? (12)	Probable producing horizon or zone[a]
51-71-6CBA-1	Mador	D	208.5	–	None	4168	51.64	5-25-73	–	–	No	6
51-71-6CBA-2	Mador	D	400R	–	EP	–	–	–	–	–	Yes	6
51-71-CBA-3	Mador	D	Spring	–	–	–	–	–	6R	–	Yes	6
51-71-30BAC	Marshall	S	Spring	–	–	4275	0	–	200R	9-27-73	Yes	5
51-72-4AAc	Wagensen	S	Spring	–	–	4200	0	4- 6-73	5E	–	Yes	1
51-72-4CDC	Oedekoven	S	149.7	–	WM	4215	80.76	4- 6-73	–	–	Yes	3
51-72-4BAA	Wagensen	D	352R	–	EP	–	30-40R	–	10R	–	Yes	6
51-72-5ADD-1	Oedekoven	D	450R	1958R	EP	–	160R	–	10R	–	Yes	6
51-72-5ADD-2	Oedekoven	S	–	–	WM&EP	–	–	–	–	–	Yes	?
51-72-7AAC	Wagensen	S	Spring	–		4200	0	–	60-70R	–	No	1
51-72-7ACA	Schoolhouse	D	–	–		–	5.6	9-26-73	–	–	Yes	?
51-72-7DAC	Daly	S	–	–	EP	–	–	–	–	–	Yes	?
51-72-9CCD	Wagensen	S	Spring	–	–	4190	–	–	0.5	9-26-73	Yes	1
51-72-11DDA	Carter	S	78.3	–	WM	4275	70.12	6-25-73	–	–	Yes	3
51-72-13DDA	Marshall	S	60.9	–	EP	4232	14.07	6-24-73	–	–	Yes	6
51-72-16BDD	Wagensen	S	Spring	–	–	–	–	–	–	–	Yes	1
51-72-17CDB	Hardy	D	127R	–	EP	4350	92R	1973	7.5	–	Yes	2
51-72-18DAA	Wagensen	S	Spring	–	–	–	–	–	–	–	No	?
51-72-20AAB	Coulter	D	–	–	EP	–	–	–	–	–	Yes	?
51-72-20ACB-1	Wandler	D	60R	1966R	EP	–	–	–	–	–	Yes	2
51-72-20ACB-2	Wandler	D	118R	1973R	EP	–	–	–	100R	–	Yes	2
51-72-20ADB-1	Harned	D	250R	1970R	EP	–	–	–	–	–	Yes	3
51-72-20ADB-2	Harned	S	–	–	WM	–	–	–	–	–	No	?
51-72-20BDC	Vandekoppel	D	60R	–	EP	–	30R	–	10R	–	Yes	1?
51-72-20CBA	Vandekoppel	S	–	–	WM	–	–	–	–	–	Yes	?

[a] 1. Alluvium
2. Above Roland coal
3. Roland coal
4. Smith coal
5. Base of burned coal
6. Below Smith coal

(continued)

TABLE 5-13 (continued)

Well number (1)	Ranch or house identification (2)	Use (3)	Depth (feet) (4)	Year completed (5)	Type of power (6)	MP elev. (feet) (7)	Depth to water feet (8)	Depth to water date (9)	GPM (10)	Date (11)	Used? (12)	Probable producing horizon or zone[a]
51-72-200CDB	Hladkey	S	68	–	WM	4275	12	–	–	–	No	1
51-72-20DDB	Hladkey	S	–	–	WM	–	12	–	–	–	Yes	?
51-72-21BCB	Coulter	D	48R	–	EP	–	–	–	–	–	Yes	6
51-72-22DAC	AMAX coal	S	–	–	WM	–	–	–	–	–	No	?
51-72-22DCC	–	S	149.7	1973E	WM	4270	24.55	6-24-73	–	–		2
51-72-28DAB-1	AMAX coal	D,S	–	–	EP	–	–	–	–	–	Yes	?
51-72-28DAB-2	AMAX coal	S	–	–	WM	–	–	–	–	–	No	?
51-72-29DBB	Hladkey	D	–	–	EP	–	–	–	–	–	Yes	?
51-73-13ADB	Daly	S	77.0	–	WM	4295	60.4	7- 7-73	–	–	Yes	2
52-72-24BAA	Rourke	S	48.9	–	WM	4055	12.09	6-24-73	–	–	Yes	6
52-72-25BDB	Clark	D,S	Spring	–	–	–	–	–	10R	–	Yes	6
52-72-26AD	Clark	S	–	–	–	–	6+	9-27-73	–	–	Yes	?
52-72-29DBD	Thorpe	S	Spring	–	–	–	(See notes)		–	–	Yes	2
52-73-24DDD	–	S	115.6	–	EP	–	25.09	4- 6-73	2.0+	4- 6-73	Yes	2
52-73-25DCC	–	D,S	–	–	WM	–	–	–	–	–	No	?

[a] 1. Alluvium
2. Above Roland coal
3. Roland coal
4. Smith coal
5. Base of burned coal
6. Below Smith coal

TABLE 5-13 (continued)

Explanation of column headings:

(1) 51-71-6CBA-1 example: 51 = T 51 N, 71 = R 71 W, 6 = Section, CBA = NE¼ NW¼ SW¼, 1 = well number 1 in this location.

(2) Tentative information based on currently available information.

(3) D = domestic, S = stock

(4) Distance in feet from measuring point (MP) to static water level.

(5) R = reported. E = estimated by Fisk.

(6) EP = electric power. WM = windmill.

(7) MP = measuring point (usually top of casing). Plus or minus 10 feet accuracy.

(8) Distance in feet from measuring point to static water level.

(9) Date of water level observation data.

(10) GPM = gallons per minute. R = reported. E = estimated. + = plus, or more than.

(11) Date of yield data.

(12) Present use status. Yes = currently used. No = currently not used.

Supplementary Notes:

51-71-6DBA-1. USGS card data. Valley side slope. Drilled well in pit about 8 feet deep, 6-inch casing, no pump, no power. MP about 8 feet below land surface. Water temperature 55° F (bailer sample), conductivity 1050 on 5-25-73.

51-71-6CBA-2. USGS map data. New well about 10 feet north of well 51-71-6DBA-1. Conductivity 1000 on 5-25-73. Photo by Fisk on 9-26-73.

51-71-6DBA-3. USGS map data. Conductivity 500 on 5-25-73. Photo by Fisk on 9-26-73.

51-71-30BAC. USGS map data. Spring flowing out of hillside. Evidently the source of the Little Powder River. Discharge about 0.5 second feet (visual estimate by Fisk on 9-27-73). Three photos by Fisk on 9-27-73. Norman King of USGS (Denver) believes that this spring indicates the rate of underflow through the coal from the south.

51-72-4AAC. USGS card data. Developed spring in bottom of upland swale. Water temperature 42° F, conductivity 2350, pH 6.0 on 4-6-73.

51-72-4CDC. USGS card data. Upland near ridge top. Drilled well with 6 inch casing. MP about 0.5 feet above land surface. Good measurements. Water temperature 46.5° F, conductivity 1700, pH 6.0 on 4-6-73.

TABLE 5-13 (continued)

51-72-4BAA. Pump setting 160 feet reported. Photo by Fisk on 9-27-73.

51-72-5ADD-1. Pump setting 200 feet reported. Good quality water, slight show of gas reported. Discharge reported about 10 gpm for one hour, then pump is off for 15 to 20 minutes, then 10 gpm for an hour, etc. Photo by Fisk on 9-26-73.

51-72-5ADD-2. Photo by Fisk on 9-26-73.

51-72-7AAC. Reported yield of 60-70 gpm for 2 or 3 months, then dry-up for several months repeat cycle. Photo by Fisk on 9-26-73, no visible flow at that time.

51-72-7ACA. School well in shed behind school. MP about 0.5 feet above land surface. Two photos by Fisk on 9-26-73. Water softener used.

51-72-7DAC. Photo by Fisk on 9-27-73.

51-72-9CCD. Discharge about 0.5 second feet (visual estimate by Fisk) on 9-26-73.

51-72-11DDA. USGS card data. Upland. Drilled well with 6-inch casing. MP about 2.6 feet above land surface. Conductivity 3600 on 6-25-73. Photo by Fisk on 9-26-73.

51-72-13DDA. USGS card data. Valley side slope. Stream (Little Powder River) in valley. Drilled well with submersible pump, 6 inch casing. MP about 13 feet above land surface. Water temperature 50.5° F, conductivity 925 on 6-24-73. Old homestead no longer occupied. Evidently owned by Carter.

51-72-16BDD. Two-inch steel pipe extends to stock tank about 4 feet wide and 12 feet long, half-full of water on 9-26-73. Photo by Fisk.

51-72-17CDB. USGS card data. Well on top of ridge. Submersible electric pump. Conductivity 1350, pH 6.4 on 4-6-73. Photo by Fisk on 9-26-73.

51-72-18DAA. Trickle from pipe on 9-26-73. Photo by Fisk.

51-72-20AAB. Drilled by Ruby. Trench was being dug on 9-26-73 for pipe from well to prefab houses. Photo by Fisk.

51-72-20ACB-1. Well drilled with rotary on top of coal, gravel packed. Water potable but has some rust. Photo by Fisk on 9-26-73.

51-72-20ACB-2. Drilled by Western Exploration, 60 feet of sand, 5½-inch casing. Described as "real gusher." Photo by Fisk on 9-26-73.

51-72-20ADB-1. Drilled by Ruby. Photo by Fisk on 9-26-73.

51-72-20ADB-2. Photo by Fisk on 9-26-73.

51-72-20BDC. Reported pump set at about 40 feet. Reported that yield might be more with larger pump. Good quality water. Photo by Fisk on 9-26-73.

51-72-20CBA. Photo by Fisk on 9-26-73.

51-72-20CDB. USGS map data. Photo by Fisk on 9-26-73.

51-72-20DDB. Photo by Fisk on 9-26-73.

TABLE 5-13 (continued)

51-72-21BCB. Drilled by Buck Williams. Well near new house on hill. Described as "real good well." Water quality good. Photo by Fisk on 9-26-73.

51-72-22CAC. Photo by Fisk on 9-26-73.

51-72-22DCC. USGS card data. Upland valley bottom. MP 0.9 feet above land surface. Cylinder pump, 6 inch casing. Water temperature 55° F (bailer sample), conductivity 1875. Photo by Fisk on 9-26-73.

51-72-28DAB-1. Photo by Fisk on 9-26-73.

51-72-28DAB-2. Photo by Fisk on 9-26-73.

51-72-29DBB. Photo by Fisk on 9-26-73.

51-73-13ADB. USGS card data. Upland valley bottom. Drilled well, cylinder pump, 6-inch steel casing. MP 0.4 feet above land surface. Static water measured with electric tape. Water obviously high in iron. Water temperature 49.5° F, conductivity 3400, pH 6.4 on 4-7-73.

52-72-24BAA. USGS card data. Upland valley bottom. Cylinder pump, 6-inch steel casing. MP 1.4 feet above land surface. Water temperature 53° F (Bailer sample), conductivity 1050 on 6-24-73.

52-72-25DBB. Stock tank located immediately below spring on hillside. Domestic water piped from spring to Mrs. Clark's white house east of Highway 59 and to Mrs. Clark's old red house west of highway. Photo by Fisk on 9-27-73.

52-72-26ADD. Not sure if supplied by pipe from spring 52-72-25DBB. Photo by Fisk on 9-27-73.

52-72-20DBD. Water flows from spring into stock tank. Reported to flow year around. Flow on 9-26-73 about 0.1 gpm. Photo by Fisk.

52-73-24DDD. USGS card data. Valley side slope. Drilled well, 6-inch steel casing, submersible pump. MP 0.4 feet above land surface. Good measurements. Water temperature 51.5° F, conductivity 790, pH 6.4 on 4-6-73.

52-73-25DCC. Photo by Fisk on 9-27-73.

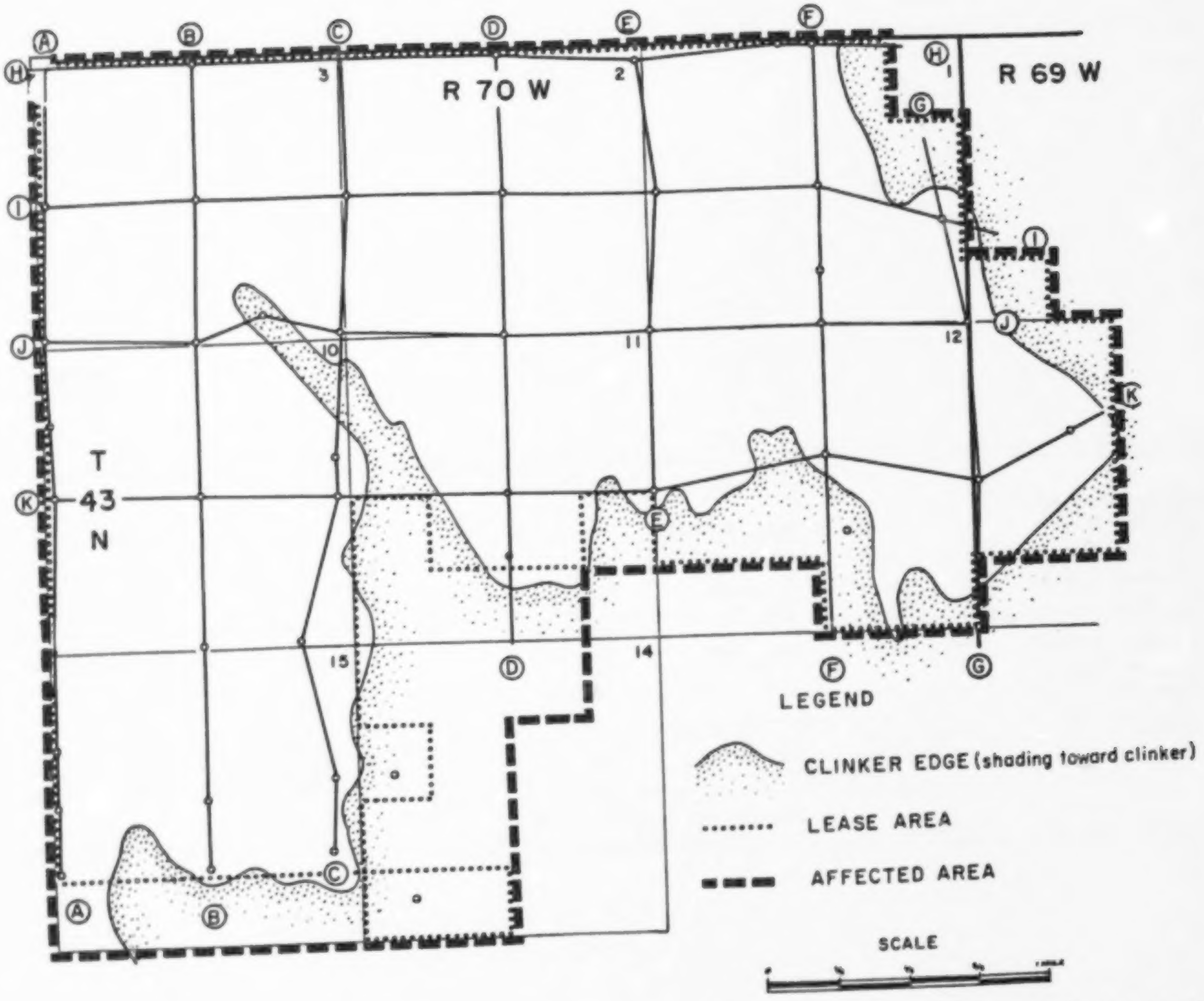

A
B
C
D
E
F
H
I
J
K
G
R 70 W
R 69 W
T
43
N
1
2
3
10
11
12
14
15
LEGEND
CLINKER EDGE (shading toward clinker)
LEASE AREA
AFFECTED AREA
SCALE

Figure 5-25. Kerr-McGee Jacobs Ranch mine, Thunder Creek area (Kerr-McGee Coal Corp., 1977).

TABLE 5-14. SUMMARY OF AQUIFER TEST DATA, KERR-McGEE JACOBS RANCH MINE
(Kerr-McGee Coal Corp., 1977)

Test well No.	Date of test	Type of test	Observ. well No.	Length of test (min.)	Prod. rate (gpm)	Final draw-down (ft)	1 Day spec. cap. (gpm/ft)	Aquifer parameters: Geol. fm[a]	Trans. (gpd/ft)	Aquif. thick. (ft)	Perm. (gpd/ft^2)	Storage coeff.	Comments
36-7	?	Pump	–	0.5	2	?	–	Sc & Co	–	10	–	–	SWL at pump bowls-no recovery after 30 min.
37-3	12-5-74	Sp cap	–	60	5	22	0.17	Co	400	70	5.7	–	Erratic pump rate
	12-5-74	Pump	9C-3	1060	5	–	–	Co	52	60	0.9	2.1×10^{-4}	Erratic pump rate
28-1	12-7-74	Sp cap	–	30	5	15.5	0.04	Co	100	70	1.4	–	Erratic pump rate
	12-7-74	Pump	4C-1	164	1.8	–	–	Co	112	38	2.9	1.3×10^{-5}	Erratic pump rate
#2	9-28-74	Sp cap	–	1440	42	0.4?	105.0	Co	100,000	108	930	–	No packer-possible leakage from overlying scoria
#3	9-28-74	Sp cap	–	1440	49	145	0.34	FU	500	55	9	–	–

[a] Sc = Scoria
Co = Coal
W = Wasatch
FU = Fort Union

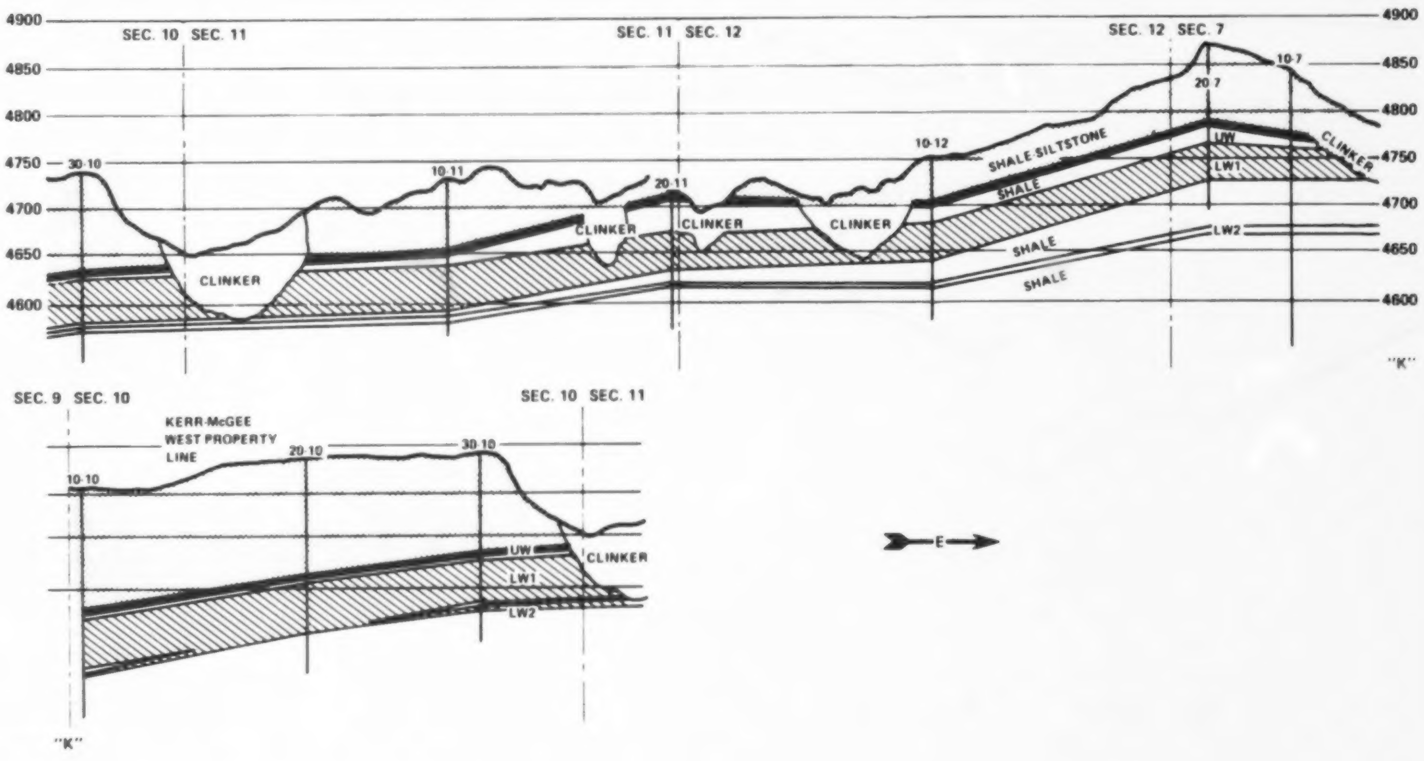

4900
4850
4800
4750
4700
4650
4600
SEC. 10 SEC. 11
SEC. 11 SEC. 12
SEC. 12 SEC. 7
30-10
10-11
20-11
10-12
20-7
10-7
CLINKER
SHALE-SILTSTONE
SHALE
UW
LW1
LW2
"K"
SEC. 9 SEC. 10
SEC. 10 SEC. 11
KERR-McGEE WEST PROPERTY LINE
10-10
20-10
30-10
E

Figure 5-26. Kerr-McGee Jacobs Ranch mine cross section K-K (Kerr-McGee Coal Corp., 1977).

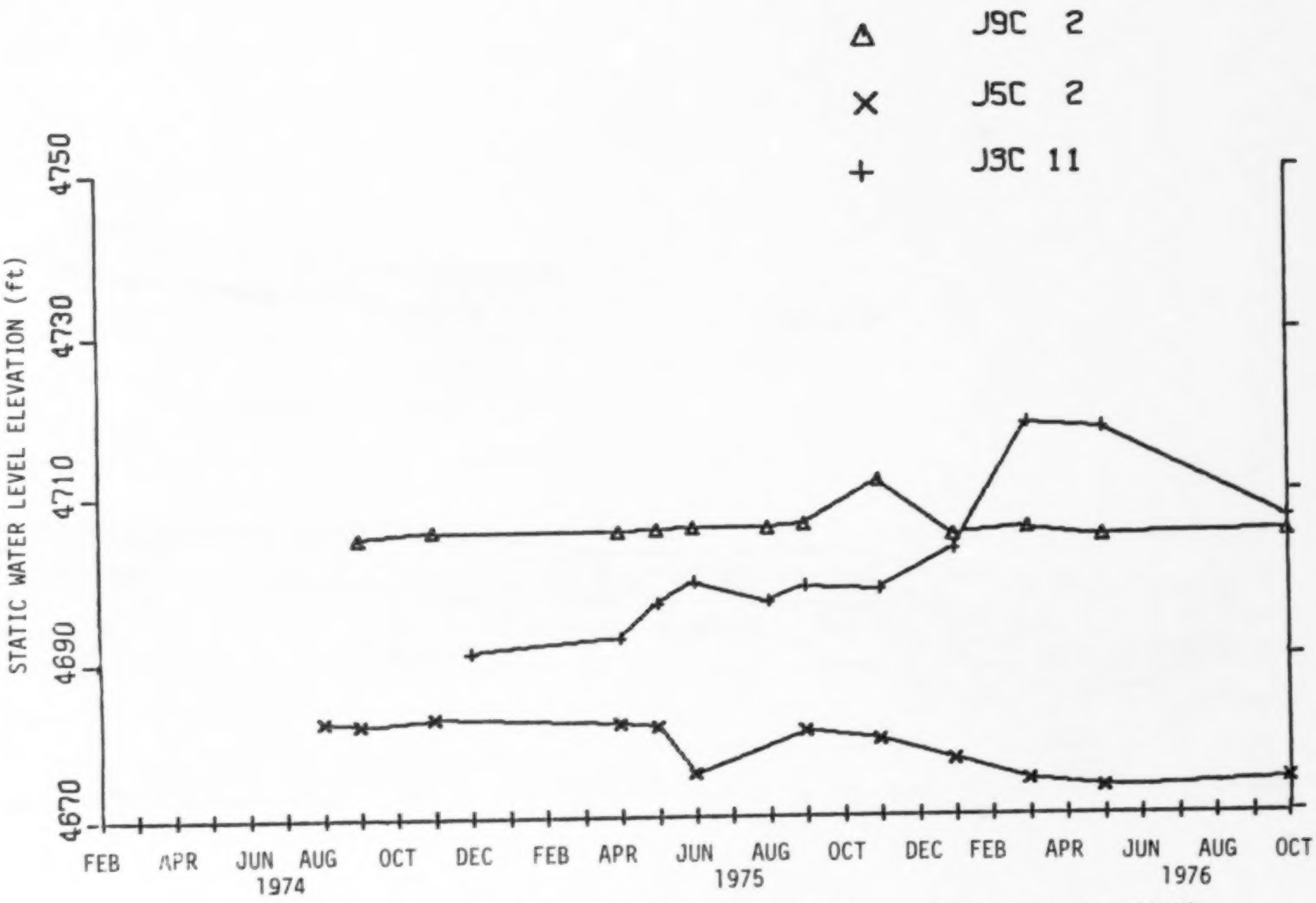


Figure 5-27. Static water levels – Jacobs Ranch mine (Kerr-McGee Coal Corp., 1977).

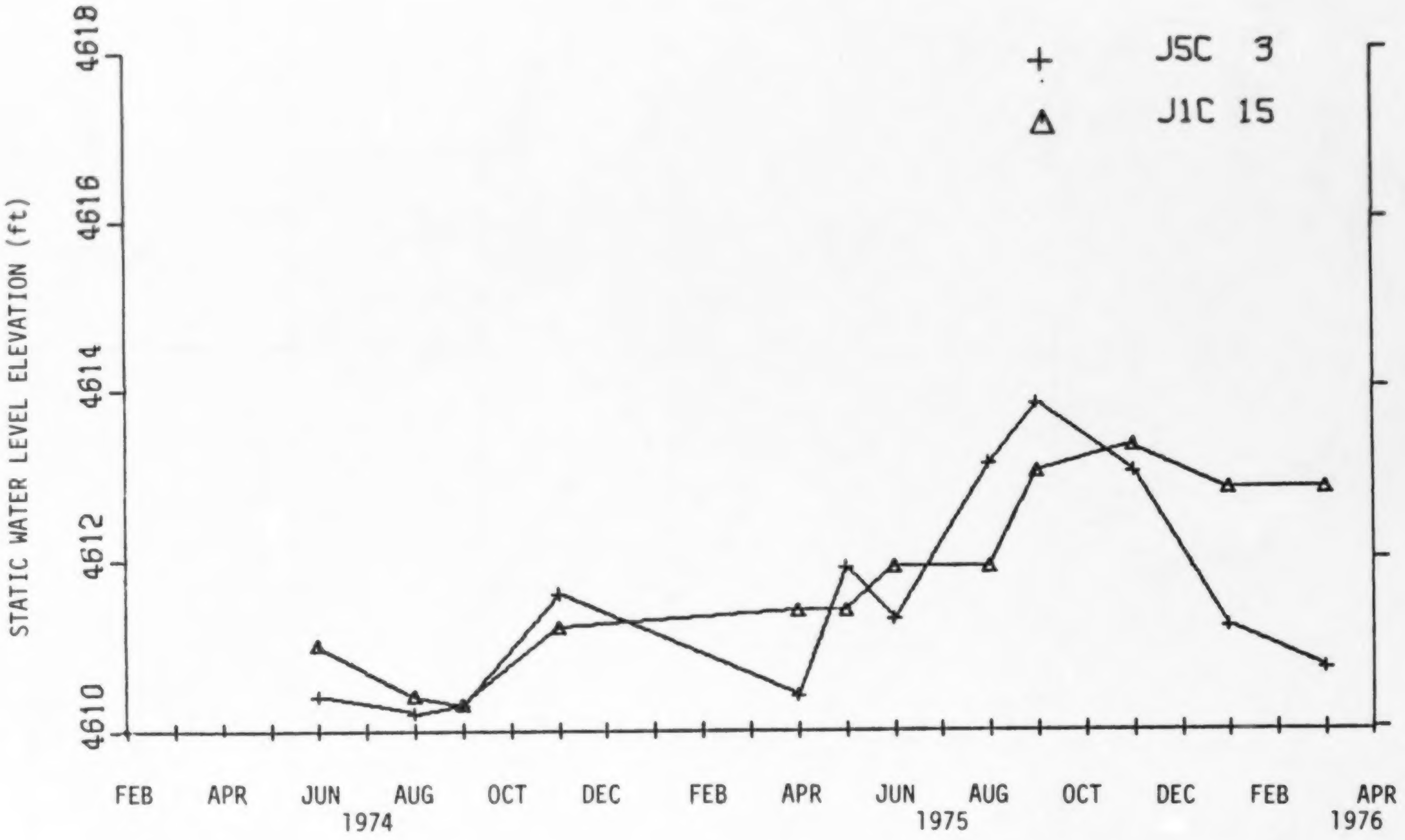


Figure 5-28. Static water levels – Jacobs Ranch mine (Kerr-McGee Coal Corp., 1977).

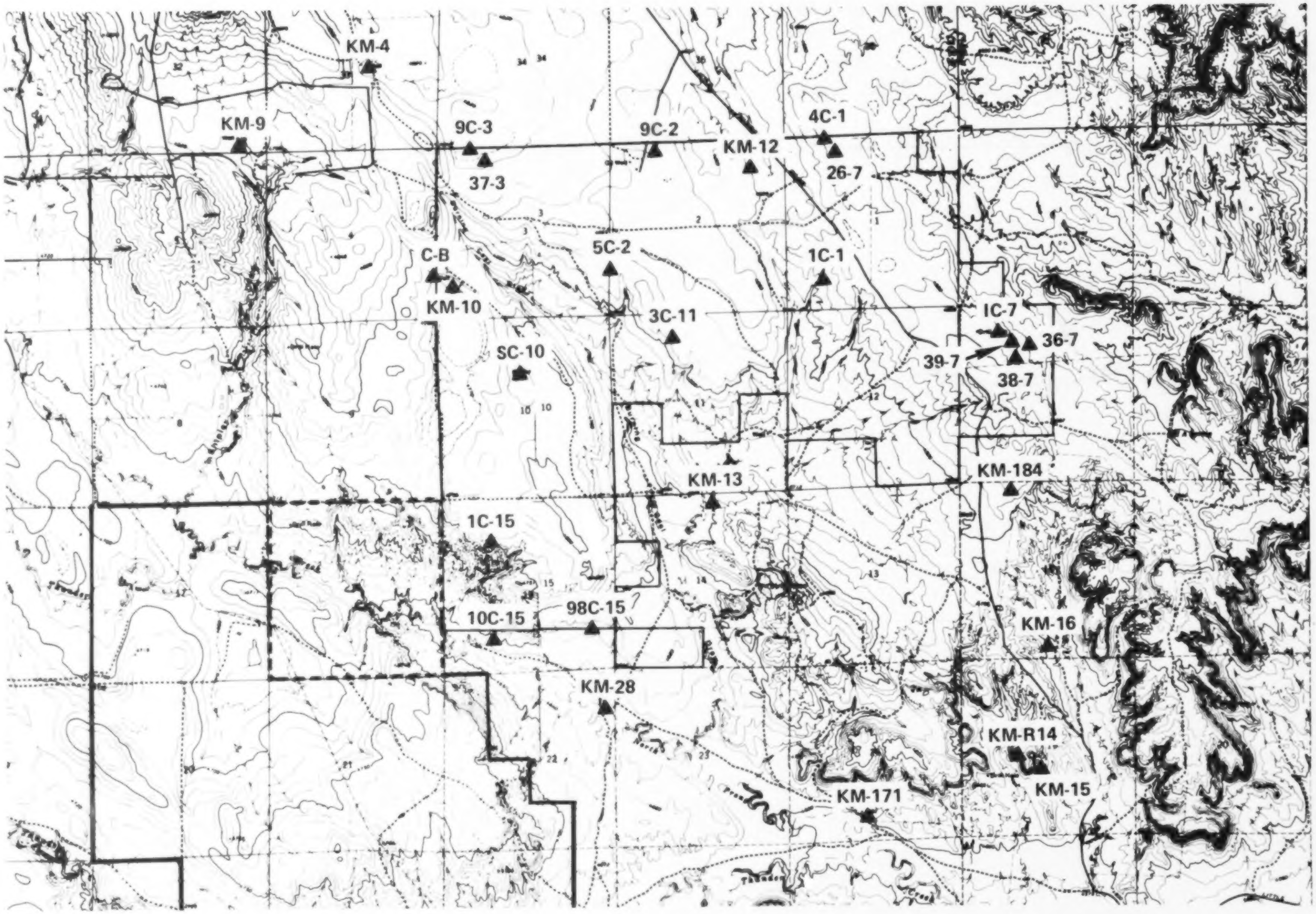

KM-4
KM-9
9C-3
37-3
9C-2
KM-12
4C-1
26-7
C-B
KM-10
5C-2
1C-1
3C-11
IC-7
36-7
39-7
38-7
SC-10
KM-13
KM-184
1C-15
10C-15
98C-15
KM-16
KM-28
KM-R14
KM-15
KM-171

Figure 5-29. Kerr-McGee Jacobs Ranch mine well locations (Kerr-McGee Coal Corp., 1977).

TABLE 5-15. DESCRIPTION OF MONITOR WELL COMPLETIONS AT JACOBS RANCH MINE (Kerr-McGee Coal Corp., 1977)

	Location						Depths (ft.)							Diameters (in.)			
Well No.[a]	North	East	Sec.	(N)	(W)	Grd. elev. (ft abv. msl)	Total	Csg.	Packer base	Perf. intv.	Gravel pack	Type of hole	Geol fm[b]	Drill bit	Csg.	Type csg.	State permit
1C-1	1115288	486954	1	43	70	4341.3	180	180	None	80-180	X	-	Coal	4	1-1/4	PVC	28904
1C-7	2223011	492322	7	43	69	4892.2	140	140	None	40-140	X	-	Coal	4	1-1/4	PVC	28905
1C-15	1107229	476318	15	43	70	4756.2	185	185	None	85-185	X	-	Coal	4	1-1/4	PVC	28906
3C-11	1113220	482038	11	43	70	4804.8	160	160	None	60-160	X	-	Coal	4	1-1/4	PVC	28907
4C-1	1119276	487046	1	43	70	4875.4	180	180	None	80-180	X	-	Coal	4	1-1/4	PVC	28908
5C-2	1115375	489363	2	43	70	4820.9	195	195	None	95-195	X	-	Coal	4	1-1/4	PVC	28909
5C-3	1115336	474966	3	43	70	4773.4	220	220	None	120-220	X	-	Coal	4	1-1/4	PVC	28910
9C-2	1119281	481732	2	43	70	4854.8	200	200	None	100-200	X	-	Coal	4	1-1/4	PVC	28911
9C-3	1119093	476362	3	43	70	4807.6	240	240	None	140-240	X	-	Coal	4	1-1/4	PVC	28912
9C-10	1112533	478736	10	43	70	4800.6	170	170	None	70-170	X	-	Coal	4	1-1/4	PVC	28913
28-1	1119114	487102	1	43	70	4877.4	160	160	90	88-160		C	Coal	9	5	PVC	28708
36-7	1112770	492819	7	43	69	4847.7	80	80	None	40-80	X	C	Sc & Co	9	5	PVC	28706
37-3	1119000	476474	3	43	70	4810.5	240	240	160	160-240	X	C	Coal	9	5	PVC	28707
37-7	1112775	492886	7	43	69	4842.4	76	76	None	36-76	X	C	Sc	5-1/8	2	PVC	28709
38-7	1112768	492598	7	43	69	4869.9	120	120	None	82-120	X	C	Coal	5-1/8	1-1/4	-	28710
39-7	1112870	492464	7	43	69	4882.9	140	140	None	100-140	X	C	Coal	5-1/8	2	-	28711
98C-15	1104610	479250	15	43	70	4660	81	-	-	-	-	-	-	4-3/4	-	-	-
102C-15	1104240	476450	15	43	70	4642	50	-	-	-	-	-	-	5	-	-	-
#2W	1109070	841920	11	43	70	4683	180	163	25	55-163	X	W	Sc	7-7/8	6	Steel	29425
#3W	1104590	480900	14	43	70	4683	679	645	190	413-600	-	W	Sand	8-3/4	6-5/8	Steel	29426

[a] C = Converted core hole
W = Water well

[b] Sc = Scoria
Co = Coal

Sun Oil Cordero –

Groundwater at the Cordero mine has not received extensive treatment in the Cordero mining plans or impact statements. Brief descriptions of the occurrence and quality of water have been offered, but supporting maps are not presented.

Groundwater exists in the Wasatch Formation, the coal beds, the alluviated area of the Belle Fourche River, and probably in the scoria. Cordero has not published any pump test results to aid in the evaluation of these aquifers, although the environmental impact statement states that aquifer characteristics are probably similar to those at Belle Ayr South (U.S. Geological Survey, 1976). Field observations at Cordero indicate that the overburden is generally dry, with the exception of several lenticular sandstone beds. Some water does emanate from the coal seams, and Cordero estimates that it will pump between 70,000 and 100,000 gpd from the pit. No information on scoria aquifers or alluvial aquifers has been located.

Water levels were fairly stable during premining activity, as shown on Figure 5-30. These levels were published in Cordero Mining Co. (1976).

Wyodak –

The Wyodak mine has been mining coal since 1925. When compared with the planned mines on Federal leases, Wyodak is a relatively small strip mine. However, because mining has proceeded for a long period of time, Wyodak's hydrogeology bears scrutiny.

Wasatch and alluvial aquifers are given minimal treatment in Wyodak Resource Development Corp. (1977). Wasatch aquifers are described as having "low permeability," although no pump test data are given to substantiate this statement. Donkey Creek runs north past the south Wyodak pit and turns to the east just in front of the Neil Simpson Power Plant at Wyodak. From field observations, it is estimated that there is no more than 20 feet of alluvium along the streambed of Donkey Creek. Although parts of the alluvium are saturated, the alluvial aquifer is a minor one.

Three separate scoria aquifers are beneath Wyodak leased lands. As shown on Figure 5-31, these are the East Burn, the "21" Burn, and the Ditto Lake Burn (Wyodak Resource Development Corp., 1977). Saturated thicknesses in the East Burn are on the order of 20 to 30 feet. Wyodak feels that a relatively impervious layer of slaked coal and ash separates the coal beds from the highly permeable East Burn scoria. The "21" Burn is bordered by coals on the east and by layers of clays, fine sands, and fluvially deposited ash, slaked coal, and scoria to the west. Wyodak's consultants feel that this layered material to the west has a low permeability and serves to isolate Wyodak's coal beds from the Ditto Lake aquifer. The Ditto Lake Burn, covering 688 acres, is the largest of the Wyodak scoria areas, and it also has the most water in storage. Ditto Lake receives internal drainage from local high areas, and this runoff serves to recharge the scoria aquifer. Pumping tests indicated porosities of 13 percent (Wyodak Resource Development Corp., 1977) and specific capacities of 18 gpm/ft (Rahn, 1976). The aquifer discharges to the coal at the western

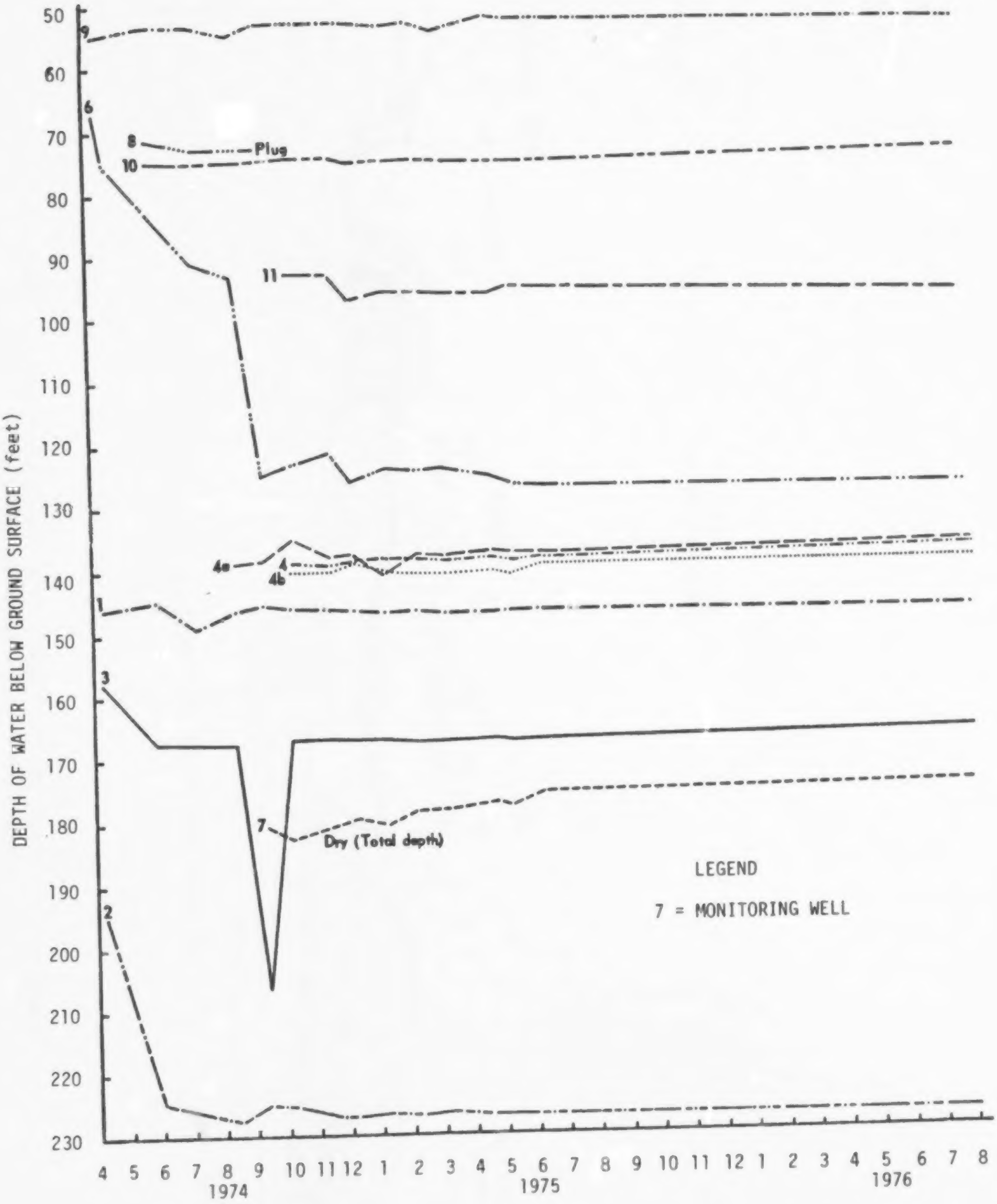


Figure 5-30. Water levels of monitor holes at Sun Oil Cordero mine (Cordero Mining Co., 1976).

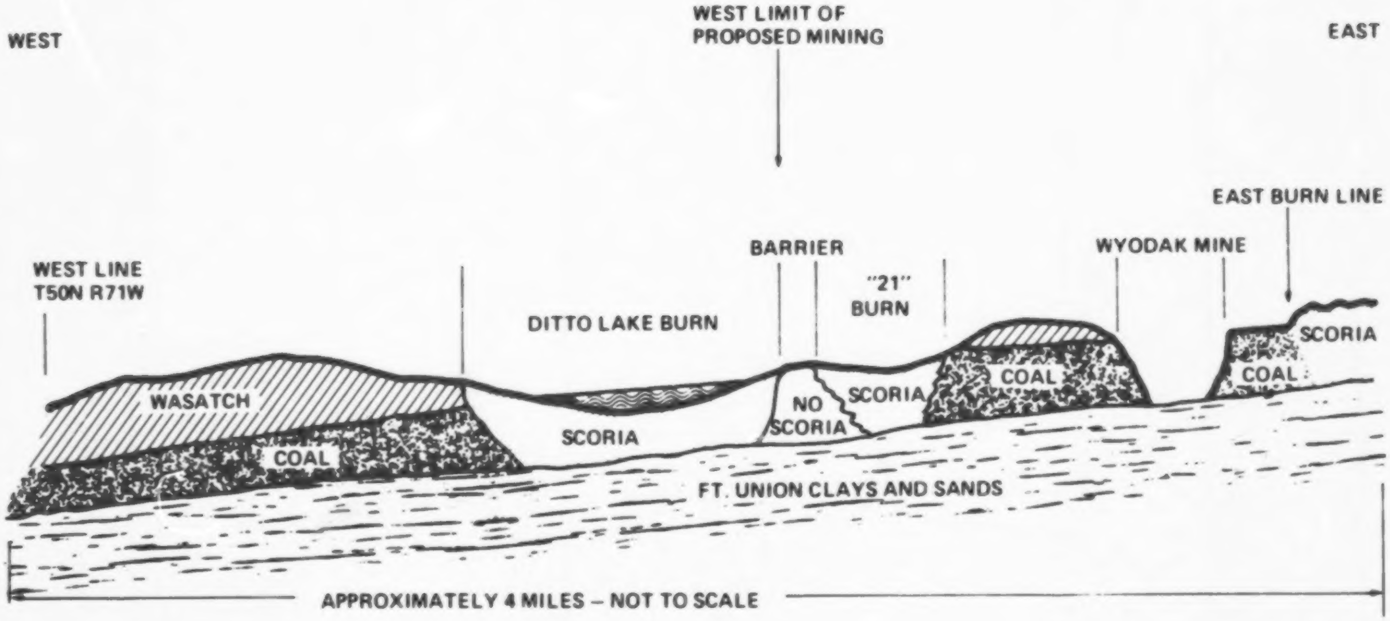

WEST
WEST LIMIT OF PROPOSED MINING
EAST
EAST BURN LINE
BARRIER
WYODAK MINE
WEST LINE T50N R71W
"21" BURN
DITTO LAKE BURN
SCORIA
COAL
WASATCH
NO SCORIA
SCORIA
COAL
SCORIA
COAL
FT. UNION CLAYS AND SANDS
APPROXIMATELY 4 MILES – NOT TO SCALE

Figure 5-31. Idealized east-west cross section of Wyodak site (Wyodak Resources Development Corp., 1977).

edge of the burn, to the layered rocks at the eastern edge, and to evapotranspiration.

The coal aquifers at Wyodak are characterized by low permeability according to Wyodak Resources Development Corp. (1977).

The north pit is reported to make "very little water" even though water levels are 90 feet above the pit floor only 2,300 feet to the west (Wyodak Resources Development Corp., 1977). Observations at the south pit indicate that the largest flows are from fractures near parting layers between the Roland and Smith coals.

As its potentiometric surface map for its 1977 Mining Plan Update, Wyodak submitted a partial copy of a U.S. Geological Survey map by King (1974). This map (Figure 5-32) included few points on or near the mine, and much of the data was from wells with openings in more than one aquifer.

Wyodak Resources Development Corp. (1977) states that there is a groundwater divide at the mine. Flows west of the mine are said to be confined in the coal seam. To the east, water is said to be unconfined and flowing to the east in Wasatch Formation aquifers. Figure 5-33 shows the effects of 50 years of mining on water levels near the Wyodak pit.

Wyodak's groundwater monitoring stations and monitoring schedules are shown on Figure 5-34 and in Table 5-16.

MODIFIED HYDROGEOLOGY

Watershed Characteristics

Mining of coal will result in several changes in the surface water system and its relation to groundwater. The most conspicuous change will be a general lowering of the land surface where the coal seams are removed. The overall decrease in volume of material (coal and overburden) disturbed by mining will be slightly less than the volume of coal removed because the overburden increases slightly in volume when broken up and replaced.

The lowering of the land surface will increase areas of internal drainage, or closed basins, on all watersheds affected by mining. The water budget of a closed basin created by mining will determine if the basin forms a perennial lake or becomes dry for long periods. Surface runoff is a critical factor in the budget and will determine if a basin that lies below the water table becomes a sink for groundwater or a source of recharge. Existing methods of surface runoff prediction may greatly overestimate runoff volumes (Lowham, 1976). If runoff volume is much less than estimated, a basin may be a groundwater sink and concentrate all salts brought in by surface and subsurface flow.

Recharge quantities under postmining conditions currently are unknown. In interstream areas, recharge will depend on modified hydrologic properties of replaced soil and the configuration of the soil surface. The surface may be artificially pitted to encourage infiltration and storage of soil water for plants. It is not known if this water will move deep into the subsurface. Most or all of the water may be consumed by evapotranspiration.

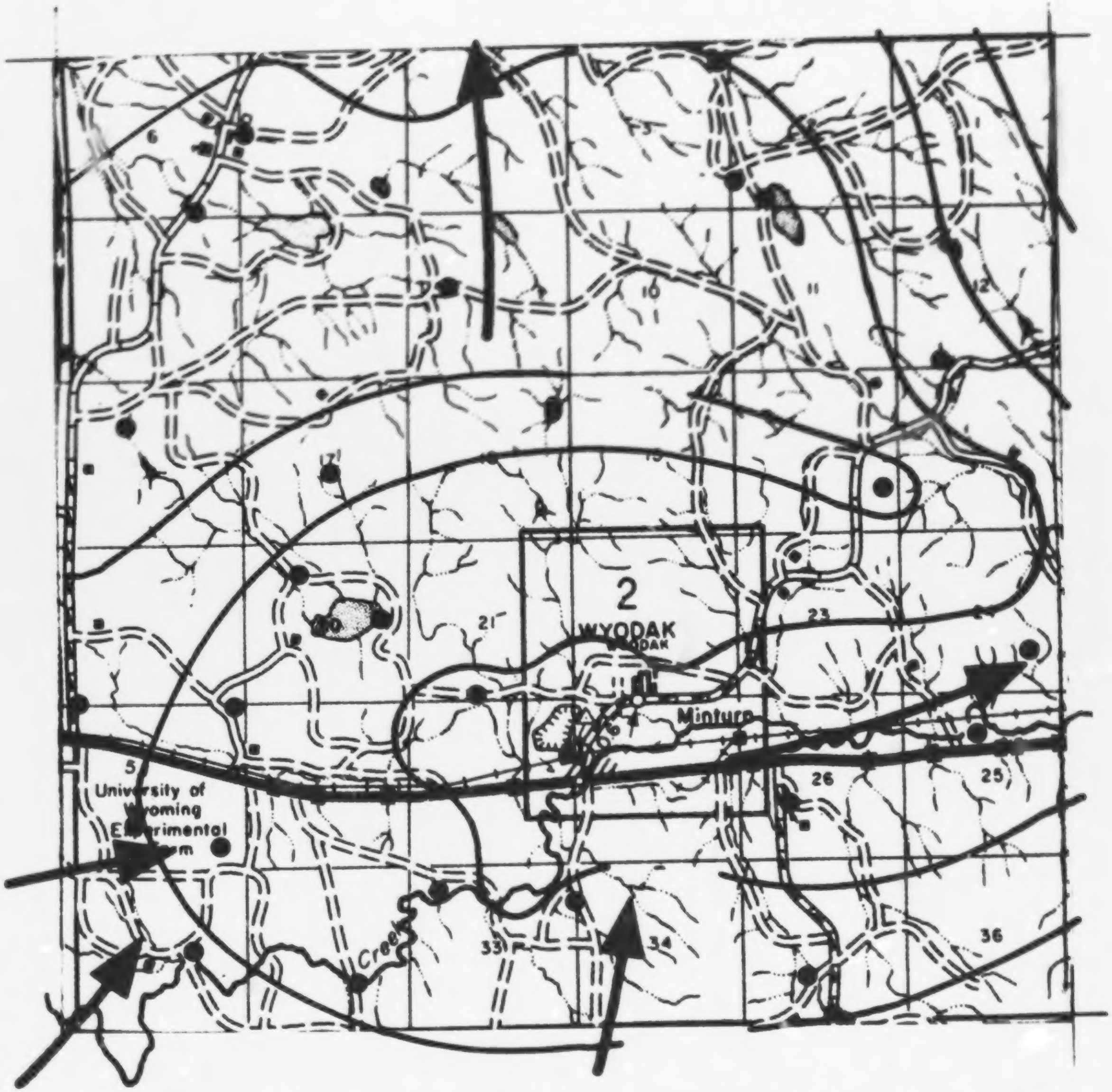

6
12
10
11
2
WYODAK
21
20
23
Minturn
5
University of Wyoming Experimental Farm
26
25
Creek
33
34
36

Figure 5-32. Contours of water table, Wyodak area (from U.S. Geological Survey map I-848-F, King, 1974).

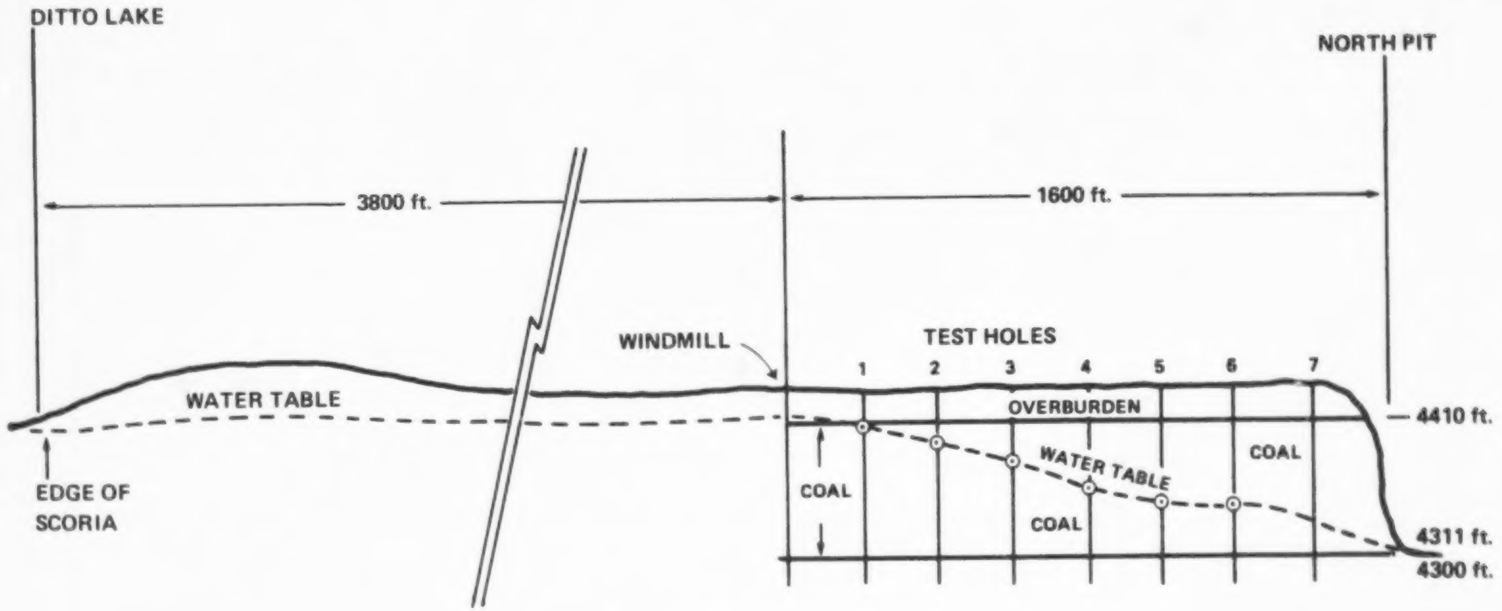

DITTO LAKE
NORTH PIT
3800 ft.
1600 ft.
WINDMILL
TEST HOLES
1
2
3
4
5
6
7
WATER TABLE
OVERBURDEN
4410 ft.
COAL
WATER TABLE
COAL
COAL
EDGE OF
SCORIA
4311 ft.
4300 ft.

Figure 5-33. Effect of 50 years of mining in Wyodak north pit upon water table (after Wyodak Resources Development Corp., 1977).

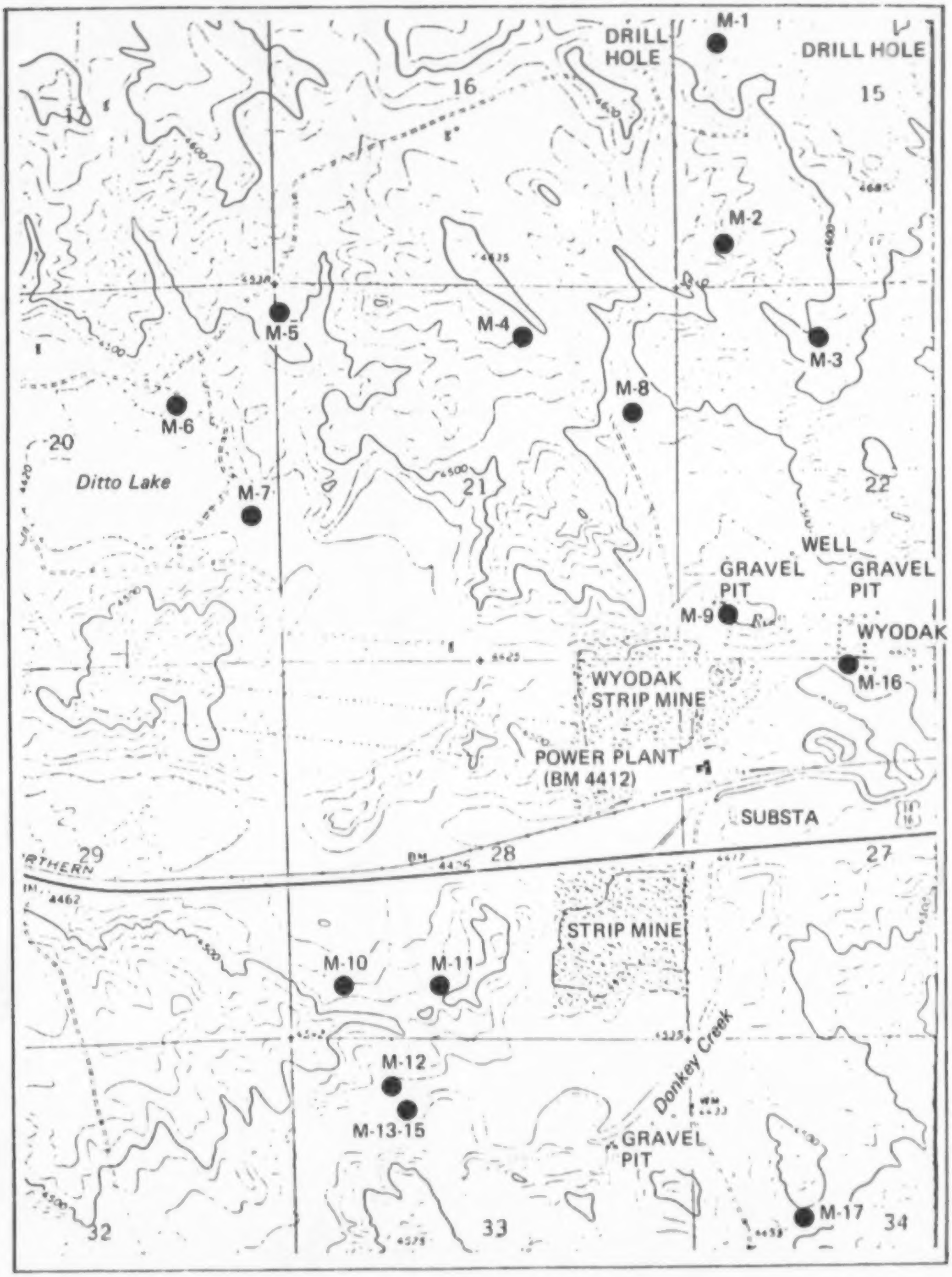

DRILL HOLE
M-1
DRILL HOLE
16
15
17
M-2
M-5
M-4
M-3
M-8
M-6
20
Ditto Lake
M-7
21
22
WELL
GRAVEL PIT
GRAVEL PIT
M-9
WYODAK
WYODAK STRIP MINE
M-16
POWER PLANT (BM 4412)
SUBSTA
29
28
27
STRIP MINE
M-10
M-11
M-12
M-13-15
Donkey Creek
GRAVEL PIT
M-17
32
33
34

Figure 5-34. Locations of monitoring wells, Wyodak mine (Wyodak Resources Development Corp., 1977).

TABLE 5-16. WYODAK GROUNDWATER MONITORING STATIONS
(Wyodak Resources Development Corp., 1977)

No.	Name	Zone monitored	Water quality	Water level
1	3-76	Wyodak coal	Every 6 mos. Start 1992	Every 6 mos. Start 1977
2	5-76	Wyodak coal	Every 6 mos. Start 1992	Every 6 mos. Start 1977
3	13-76	Sands above coal	Every 6 mos. Start 1992	Every 6 mos. Start 1977
4	11-76	Sands above coal	Every 6 mos. Start 1992	Every 6 mos. Start 1977
5	USGS	Wyodak coal	Every 6 mos. Start 1992	Every 6 mos. Start 1977
6	Ditto Ob-2	Scoria	No check planned	Every 6 mos. Start 1977
7	Ditto Ob-1	Scoria	Every 6 mos. Start 1992	Every 6 mos. Start 1977
8	Windmill	Wyodak coal	Every 6 mos. Start 1992	Every 6 mos. Start 1977
9	8-76	Wyodak coal	Every 6 mos. Start 1992	Every 6 mos. Start 1977
10	14-76	Sands below coal	Every 6 mos. Start 1977	Every 6 mos. Start 1977
11	15-76	Sands above coal	Every 6 mos. Start 1977	Every 6 mos. Start 1977
12	Windmill	Wyodak coal	Every 6 mos. Start 1977	No check planned
13	USGS #1	Alluvium	No check planned	Every 6 mos. Start 1977
14	USGS #2	Lower Wyodak bed	No check planned	Every 6 mos. Start 1977
15	USGS #3	Upper Wyodak bed	No check planned	Every 6 mos. Start 1977
16	Wyodak #5	400-foot: sands below coal	Every 6 mos. Start 1977	Every 6 mos. Start 1977
17	Windmill	Scoria	Every 6 mos.	No check planned

Along streambeds established in the soil, infiltration and recharge quantities will depend on modified stream properties, such as streambed composition, sediment loads, and material beneath the streambed.

It is possible that overall quantities of recharge to the deep subsurface from rainfall and surface runoff will decrease if near-surface permeable clinker and well-sorted alluvial deposits are destroyed.

The surface hydrology and its relation to groundwater under postmining conditions can be seen to be speculative. Too few data exist to make reliable predictions at this time. Better prediction is expected as mining progresses and more data are gathered.

Soils and Infiltration Characteristics

Determining infiltration characteristics will be necessary when there is a possibility of water percolating from the surface through reclaimed areas to depths where free water may be present or where there would be free water buildup. Of particular concern are the pollutants which may be picked up and transported by these percolating waters.

The depths to which the water might percolate on a reclaimed mine site depend upon:

- The configuration of the surface, including slope inclination, slope length, surface roughness, and surface geometry
- The physical characteristics (including porosity, texture, depth structure, and collodial content) of spoil and topsoil material used for dressing
- The amount, temporal distribution, and intensity of rainfall and snowmelt; and the rates of evaporation, including potential demand and the influence of vegetation.

Rahn (1976) determined infiltration, spoils moisture content, grain size analysis, field density of spoils, overburden lithology, and laboratory calculations of permeability on samples from several mines in the Powder River Basin. Results of permeability tests are of interest as estimates of the hydraulic conductivity of the disturbed vadose zone deposits and the leaching potential. Data for two mines in the project area are given below.

Laboratory permeability values on six samples of overburden from the Wyodak mine ranged from 6.6 to 38.0 gal/day per ft^2, with an average of 14.8 gal/day per ft^2 (Rahn, 1976). Rahn also points out that the overburden at the Wyodak mine is very thin so that the final open pit will be large but with little spoils. Since the water table is high, the end result will be mainly a lake in the abandoned pit. Thus, the final vadose zone will be of minimal thickness.

Laboratory permeameter test results for overburden samples from the Belle Ayr South mine ranged from 1.8 to 38.7 gal/day per ft^2, with an average of 12.9 gal/day per ft^2.

Vadose Zone Characteristics

The vadose zone present in spoil following reclamation will consist of a heterogeneous mixture of overburden material originally present in the indigenous vadose zone, and shallow aquifer systems. The overburden material consists of sandstone, shale, carbonaceous shale, and thin or impure coal beds of the Wasatch or uppermost Fort Union Formations. Scoria, or baked shale and siltstone, may also be present, together with alluvial material.

Two consequences of modifying the vadose zone area are: (1) increased hydraulic conductivity, and (2) exposure of fresh mineral surfaces to percolating water (Rahn, 1976). The increase in hydraulic conductivity is a reflection of the overall increase in volume and porosity of spoil formations as compared to natural formations. Obviously, the new vadose zone will be highly heterogeneous and anisotropic. For example, spoil dumped into the pit by truck will tend to separate out by gravity as it tumbles down the embankment. The method of placing spoils in the pit also appears to have an effect on hydraulic properties. For example, Rahn (1976) obtained an average permeability of 450 gpd/ft^2 at the Hidden Water Creek mine with dragline-emplaced spoils, but only 4 gpd/ft^2 at the Bighorn coal mine with scraper- and bulldozer-emplaced spoils.

A consequence of the increased hydraulic conductivity of the vadose zone is that infiltrated surface water will migrate more readily through the deposits, leaching salt into the shallow aquifers. Rahn (1976) described the mechanism involved in leaching as follows:

> "Rocks are generally broken during mining, thus allowing fresh mineral surfaces to be exposed to percolating waters. While precise hydro-geochemical reactions are difficult to predict, it can be stated ... that the equilibrium soil-water-mineral conditions which had been established ... over thousands of years are changed by mining, and with the infiltration of infiltrating rainwater or percolating groundwater in the spoils, more rapid weathering reactions can commence."

Observations by Rahn at several mine sites in the Powder River Basin illustrated that the salinity of water samples from the spoils was markedly greater than in native groundwater.

The manner in which surface water is applied to the spoil pile area may have an effect on leaching in the vadose zone. If the area becomes inundated, for example by flood water, water will move downward in the saturated state, leaching and transporting salts through large cracks or pores. With rainfall or light application of surface water, however, water will move downward in the unsaturated state. Consequently, water movement will be preferentially in the smaller pore spaces. Field experiments (Biggar and Nielsen, 1967) on leaching have shown that greater leaching occurs with unsaturated flow than with saturated flow. That is, the potential effect on groundwater quality by unsaturated flow following a rain is much greater than from surface inundation. However, because of the slow velocity of unsaturated flow, the effects may not be evident for years or centuries.

Another consequence of modifying the hydrogeologic properties of the vadose zone at mine sites is possible. In particular, perching layers may be disrupted by stripping. Consequently, water moving laterally through mounds in the vadose zone will intersect and flow into the modified region, and move downward toward the water table. Leaching will, therefore, result around the periphery.

Aquifer Characteristics

In general, considerable disruption of aquifer characteristics can occur during mining. As the coal aquifer commonly is the most productive and the coal is to be removed, in one sense the aquifer is destroyed. However, in this discussion, the concern is with the reclaimed area, namely the spoils. In a sense, the aquifer will remain, but the materials will be different than those originally present and the hydraulic characteristics will be different. Modifications of the vadose zone have been previously described. Groundwater at most mines is in the coal, in the underlying materials, and sometimes in the overburden. The coal and overburden vary greatly in the degree of consolidation; however; groundwater is generally considered to be moving through fractured consolidated rock except for the alluvium.

Three major cases to consider are:

- Removal of coal and replacement with spoils;
- Removal of alluvium and replacement with spoils; and
- Removal of overburden and replacement with spoils.

Rahn (1976) reported on two pump tests in spoils near Sheridan, Wyoming. However, the test at the Big Horn Mine yielded very questionable results and the reported values of transmissivity are considered unreliable. At the Hidden Creek Mine, a 27-hour pump test was conducted on a well tapping about 33 feet of spoils. About 21 gpm were pumped and the specific capacity was 1.7 gpm per foot of drawdown. The transmissivity was about 11,000 gpd per foot and the storage coefficient was 0.12. With an average saturated thickness of 24.5 feet, the permeability of the spoils was 450 gpd per square foot. Laboratory permeabilities reported by Rahn for spoils probably have little meaning with respect to aquifer characteristics. Additional pump tests are needed to assess the hydraulic characteristics of spoils.

Removal of Coal—

Transmissivities for coal aquifers in the Gillette area commonly range from about 100 to 3,500 gpd per foot. Values less than 1,000 gpd per foot are common and are typical of fractured hard rock. Replacement of coal by spoils would appear to result in an increased transmissivity, particularly if coarse-grained overburden is predominant in the spoils. However, a predominance of fine-grained overburden could result in a lower transmissivity. Also, the spoils are unconsolidated in macrostructure. Small pieces of relatively consolidated, fractured materials may remain in the spoils. In any case, the net surface area exposed would appear to be greatly increased. Also, groundwater may flow through spoils as if it were a granular porous medium as opposed to a fractured hard rock aquifer. The storage coefficient would appear to be much greater for spoils than for coal, and obviously the porosity of spoils would be greater. The geochemical composition of the spoils is greatly different from that of coal.

Removal of Alluvium—

The hydraulic characteristics of alluvium are poorly known in the Gillette area. However, the transmissivity is likely low because of the small saturated thickness. Presently, the alluvium serves as the point of interchange between surface water and groundwater. That is, percolating streamflow in some areas passes through the alluvium to underlying formations. Also, groundwater moving from underlying formations in some areas passes through the alluvium and enters streams to become surface water. The replacement of alluvium with spoils could have profound effect on surface water as well as groundwater. More or less percolation from streamflow could occur than under the original conditions. Also, base flow conditions in the streams could be increased or decreased. It is likely that the spoils are less permeable than the alluvium. The geochemical composition of the spoils is generally different than that of the alluvium.

Removal of Overburden—

Transmissivities of several hundred to several thousand gpd per foot are common for the Fort Union and Wasatch Formations. When the materials overlying the coal are broken up and replaced as spoils, both permeability and storage coefficient should be increased. The geochemical composition of the spoils is basically the same; however, the surface area exposed is greatly increased.

SECTION 6

EXISTING GROUNDWATER QUALITY

REGIONAL

Shallow groundwaters in the project area have poor chemical quality. Analyses performed by the coal companies cover a large part of the project area, and these results indicate that few of the shallow groundwaters meet EPA drinking water standards. Other analyses of shallow waters, published by Hodson (1971), indicate that water quality can vary widely in the project area. Regional water quality was studied by the U.S. Geological Survey (King, 1974) and most waters in the area were determined to be of marginal quality. This work did not specify which analyses were from coal aquifers or from Wasatch Formation aquifers. Preliminary field tests of City of Gillette Wasatch Formation wells yielded TDS values between 1,200 and 3,800 ppm. The City mixes this poor water with higher quality water from deeper Fort Union Formation aquifers to meet drinking water standards.

Groundwaters in the Wasatch Formation are usually of the calcium sulfate type. Analyses published by the coal companies, the State of Wyoming, and the U.S. Geological Survey indicate that TDS ranges from 500 to 6,000 ppm, with most analyses falling in the 2,000- to 4,000-ppm range. The lowest values are often found in wells near surface streams, and probably reflect the interaction of the groundwater and surface water. pH values for Wasatch waters range from 7.7 to 8.1. Trace element studies conducted on Wasatch water samples by the coal companies indicate that problems possibly may exist with the following elements: arsenic, cadmium, lead, selenium, and possibly uranium.

Coal-seam waters can have dynamic characteristics, changing from calcium sulfate waters to sodium bicarbonate waters as the water migrates downdip. The ARCO Black Thunder mine's groundwater quality contains a good example of this change. Coal-seam TDS values for the project area range from 500 to 3,500 ppm with most values in the 1,000- to 3,000-ppm interval. Values for pH range from 6.9 to 8.2 in coal aquifer waters, indicating that coal aquifer waters are neutral to slightly alkaline. Trace elements of concern include, but are not limited to, arsenic, cadmium, copper, lead, and selenium.

The following discussions are based on data published by the mining companies in various documents. To properly execute the TEMPO methodology, existing groundwater quality must be studied directly adjacent to the pollution source, so that changes induced by the source can be determined. The data presented in this section yield interesting background information, but existing groundwater quality at each important pollution source must be accumulated.

During their first 2-1/2 years of operation, AMAX Belle Ayr workers have collected numerous groundwater quality samples. Although detailed sample collection procedures were not outlined in the AMAX Coal Co. (1977) mining plan update, results of several analyses were reported. Tables 6-1 through 6-4 show the maxima and minima of these results, as well as the mean values. Significant deviations occur for some parameters, indicating a dynamic quality situation or sampling and analytical inconsistencies.

In its mining plan update, AMAX states that the dominant water types within the Wasatch Formation are sodium sulfate and sodium bicarbonate. However, selected samples from the Wasatch Formation (Table 6-1) would be classified as a calcium sulfate water. AMAX should include analyses which reflect the reported sodic quality of their Wasatch waters. Sodic waters are shown to exist in the Wyodak coal seam. Table 6-2 indicates that water types vary from sample to sample and that the coal seam waters can be either sodic or calcic. These results confirm the need for further testing to pinpoint water quality types on the Belle Ayr lease. AMAX's deep Fort Union water at well station WRRI 7 has very high sulfate contents for a potable water source. AMAX did not present data on other Fort Union wells which are reportedly used for office and shop requirements. The analyses presented for the scoria pit (Table 6-3) has a close epm balance (0.97), but the reported electrical conductivity is inconsistent with the rest of the results. If this inconsistency is ignored, the scoria pit water appears to be of fairly good quality. However, the relative amounts of groundwater inflow and surface runoff that make up this pit water are unknown, and it is assumed that groundwater within the scoria is not as good as this analysis might indicate.

AMAX has published water quality data for its Eagle Butte mine in its Federal environmental impact statement and in its AMAX Coal Co. mining plan update (1977a). This summary is based primarily on the data shown in the mining plan update. Analyses were performed by the Wyoming Department of Agriculture, and equivalent balances ranged from 0.94 to 1.31. Maximum and minimum values for water on the Eagle Butte lease are given in Table 6-5. Sample collection procedures are given in Table 6-6.

The chemical quality data presented by AMAX indicate that large variations can exist in groundwater quality at the Eagle Butte lease. Although some waters are low in total dissolved solids, most waters exceed drinking water recommended standards for dissolved minerals. Eagle Butte waters are predominantly of the calcium sulfate type. AMAX has published a single analysis for each well at the lease. Quality variations with time are reportedly being studied (AMAX Coal Co., 1977a).

ARCO and the University of Wyoming have conducted fairly extensive groundwater quality tests. The University received funding from the EPA to conduct its research at Black Thunder. Tables 6-7 and 6-8 show the analysis presented in ARCO's Final Environmental Assessment (University of Wyoming, 1976). Figure 6-1 gives the well locations; Table 6-9 summarizes these data. Cation-anion balances for selected analyses yield ratios ranging from 0.84 to 1.20, indicating fairly good analytical control.

TABLE 6-1. AMAX BELLE AYR WATER QUALITY DATA—WASATCH FORMATION ABOVE THE COAL (AMAX Coal Co., 1977)

Parameter	Number of analyses	Maximum value	Minimum value	Mean	Standard deviation
Field pH (units)	1	7.5	7.5	7.5	-
Calcium	12	279.	180.	213.	30.6
Magnesium	12	208.	59.0	145.	37.2
Sodium	12	200.	113.	164.	27.6
Potassium	11	13.0	0.0	9.52	4.80
Carbonate	12	610.	0.0	101.	237.
Bicarbonate	10	705.	500.	604.	51.0
Oil and grease	12	21.6	0.0	2.55	6.08
Sulfide	4	0.9	0.0	0.3	0.408
Arsenic	5	0.007	0.007	0.007	-
Barium	5	0.5	0.5	0.5	-
Boron	5	0.6	0.0	0.164	0.246
Cadmium	5	0.014	0.01	0.0108	0.0018
Copper	5	0.01	0.01	0.01	-
Total chromium	4	0.1	0.1	0.1	-
Chromium — Cr^{+6}	1	0.01	0.01	0.01	-
Total iron	8	5.7	0.1	2.59	1.70
Dissolved iron	8	5.0	1.8	3.20	1.19
Lead	5	0.1	0.01	0.082	0.0402
Manganese	5	0.27	0.1	0.180	0.0623
Mercury	4	0.001	0.001	0.001	-
Nickel	5	0.1	0.1	0.1	-
Selenium	4	0.002	0.001	0.0013	0.0005

Notes: Values in ppm unless specified
Well station N-5
June 1972 to June 1976

(continued)

TABLE 6-1 (continued)

Parameter	Number of analyses	Maximum value	Minimum value	Mean	Standard deviation
Silver	5	0.5	0.05	0.41	0.201
Zinc	5	0.12	0.01	0.052	0.0432
Kjeldahl nitrogen	11	1.0	0.3	0.682	0.252
Conductivity (mmhos)	12	2760.	1580.	2211.	310.
Ammonia	6	0.0	0.0	0.0	-
Organic nitrogen	1	0.9	0.9	0.9	-
Nitrate + Nitrite	1	0.0	0.0	0.0	-
Chloride	12	46.0	16.0	21.9	8.17
Fluoride	9	0.6	0.3	0.511	0.105
Cyanide	4	0.02	0.008	0.011	0.006
Sulfate	12	1369.	650.	980.	205.
Phenol	5	0.034	0.0	0.0074	0.0149
MBAS	5	0.14	0.1	0.108	0.0179
BOD	1	31.0	31.0	31.0	-
COD	12	28.4	0.4	8.71	9.19
Total dissolved solids	12	2300.	1480.	1877.	250.
Suspended solids	7	178.	8.0	38.4	61.7
Suspended volatile solids	6	100.	0.0	22.3	38.7
Lab pH	11	7.9	7.2	7.53	0.211
Turbidity (JTU)	7	29.0	1.3	10.9	9.76
Total carbonate (CO_3)	11	310.	250.	294.	16.7
Hardness ($CaCO_3$)	12	1550.	742.	1138.	211.
Alkalinity ($CaCO_3$)	3	516.	346.	454.	93.8

Notes: Values in ppm unless specified
Well station N-5
June 1972 to June 1976

TABLE 6-2. AMAX BELLE AYR WATER QUALITY DATA—WYODAK COAL (AMAX Coal Co., 1977)

Parameter	Number of analyses	Maximum value	Minimum value	Mean	Standard deviation
Field pH (units)	1	7.0	7.0	7.0	-
Calcium	12	360.	180.	208.	49.1
Magnesium	12	320.	12.0	91.4	75.2
Sodium	12	640.	103.	210.	138.
Potassium	10	14.0	8.8	11.7	1.44
Carbonate	12	0.0	0.0	0.0	-
Bicarbonate	12	560.	290.	510.	74.1
Oil and grease	12	12.1	0.0	2.34	3.55
Sulfide	4	1.1	0.1	0.525	0.505
Arsenic	5	0.007	0.007	0.007	-
Barium	5	0.5	0.5	0.5	-
Boron	5	1.1	0.0	0.27	0.465
Cadmium	5	0.01	0.001	0.0082	0.004
Copper	4	0.01	0.01	0.01	-
Total chromium	4	0.1	0.1	0.1	-
Chromium – Cr^{+6}	1	0.01	0.01	0.01	-
Total iron	9	5.1	0.2	2.19	1.65
Dissolved iron	7	2.5	1.49	2.07	0.379
Lead	5	0.1	0.02	0.084	0.0358
Manganese	5	2.0	0.1	0.774	0.839
Mercury	4	0.001	0.001	0.001	-
Nickel	5	0.1	0.1	0.1	-
Selenium	4	0.001	0.001	0.001	-

Notes: Values in ppm unless specified
Well station N-3
June 1972 to June 1973

(continued)

TABLE 6-2 (continued)

Parameter	Number of analyses	Maximum value	Minimum value	Mean	Standard deviation
Silver	5	0.5	0.05	0.41	0.201
Zinc	5	2.3	0.08	0.56	0.974
Kjeldahl nitrogen	11	3.9	1.1	2.59	0.856
Conductivity (mmhos)	12	4740.	1720.	2077.	841.
Ammonia	6	1.3	0.0	0.283	0.523
Organic nitrogen	1	3.1	3.1	3.1	-
Nitrate + Nitrite	1	0.0	0.0	0.0	-
Chloride	12	31.0	3.6	9.16	7.46
Fluoride	10	1.3	0.4	0.75	0.222
Cyanide	4	0.02	0.008	0.011	0.006
Sulfate	12	3400.	680.	940.	774.
Phenol	5	0.005	0.001	0.0026	0.0013
MBAS	5	0.16	0.1	0.112	0.0268
BOD	1	20.0	20.0	20.0	-
COD	12	345.	28.0	71.6	88.4
Total dissolved solids	12	5160.	1400.	1785.	1063.
Suspended solids	8	232.	8.0	68.2	74.7
Suspended volatile solids	6	40.0	6.0	21.8	11.9
Lab pH	11	7.9	7.0	7.23	0.246
Turbidity (JTU)	8	125.	5.0	29.4	40.0
Total carbonate (CO_3)	11	270.	140.	251.	37.7
Hardness ($CaCO_3$)	12	2200.	530.	896.	422.
Alkalinity ($CaCO_3$)	3	450.	225.	373.	128.

Notes: Values in ppm unless specified
Well station N-3
June 1972 to June 1973

TABLE 6-3. AMAX BELLE AYR WATER QUALITY DATA—SCORIA PIT—WASATCH FORMATION ABOVE THE COAL (AMAX Coal Co., 1977)

Parameter	Number of analyses	Maximum value	Minimum value	Mean
Field pH (units)	1	7.6	7.6	7.6
Calcium	1	160.	160.	160.
Magnesium	1	25.0	25.0	25.0
Sodium	1	45.0	45.0	45.0
Potassium	1	18.0	18.0	18.0
Carbonate	1	0.0	0.0	0.0
Bicarbonate	1	156.	156.	156.
Cadmium	1	0.001	0.001	0.001
Copper	1	0.01	0.01	0.01
Total iron	1	0.07	0.07	0.07
Lead	1	0.01	0.01	0.01
Manganese	1	0.002	0.002	0.002
Mercury	1	0.002	0.002	0.002
Silver	1	0.05	0.05	0.05
Zinc	1	0.02	0.02	0.02
Conductivity (mmhos)	1	504.	504.	504.
Chloride	1	29.0	29.0	29.0
Sulfate	1	456.	456.	456.
Hardness	1	21.0	21.0	21.0

Notes: Values in ppm unless specified
Well station scoria pit
June 1972 to June 1976

TABLE 6-4. AMAX BELLE AYR WATER QUALITY DATA—FORT UNION FORMATION BELOW COAL (AMAX Coal Co., 1977)

Parameter	Number of analyses	Maximum value	Minimum value	Mean	Standard deviation
Field pH (units)	1	7.7	7.7	7.7	-
Calcium	12	227.	121.	157.	26.1
Magnesium	12	85.0	36.0	46.4	12.6
Sodium	12	243.	154.	220.	23.3
Potassium	9	10.0	8.8	9.33	0.377
Carbonate	12	0.0	0.0	0.0	-
Bicarbonate	12	440.	331.	398.	25.1
Oil and grease	12	6.0	0.0	1.72	2.01
Sulfide	4	3.0	0.0	1.07	1.39
Arsenic	5	0.02	0.007	0.0096	0.0058
Barium	5	0.5	0.5	0.5	-
Boron	5	0.6	0.0	0.158	0.249
Cadmium	5	0.01	0.001	0.0082	0.004
Copper	5	0.01	0.01	0.01	-
Total chromium	4	0.1	0.1	0.1	-
Chromium—Cr^{+6}	1	0.01	0.01	0.01	-
Total iron	8	2.2	0.1	0.788	0.709
Dissolved iron	8	1.9	0.27	0.853	0.537
Lead	5	0.1	0.01	0.082	0.0402
Manganese	5	0.23	0.0	0.118	0.0823
Mercury	4	0.001	0.001	0.001	-
Nickel	5	0.1	0.1	0.1	-
Selenium	4	0.001	0.001	0.001	-

Notes: Values in ppm unless specified
Well station WRRI 7

(continued)

TABLE 6-4 (continued)

Parameter	Number of analyses	Maximum value	Minimum value	Mean	Standard deviation
Silver	4	0.5	0.05	0.387	0.225
Zinc	5	0.44	0.04	0.132	0.172
Kjeldahl nitrogen	11	3.5	0.4	1.81	0.785
Conductivity (mmhos)	12	1870.	1600.	1791.	80.1
Ammonia	6	0.3	0.0	0.05	0.122
Organic nitrogen	1	1.5	1.5	1.5	-
Nitrate + Nitrite	1	0.0	0.0	0.0	-
Chloride	12	46.0	3.6	12.1	11.7
Fluoride	9	1.6	0.3	0.555	0.397
Cyanide	4	0.02	0.000	0.011	0.006
Sulfate	12	770.	600.	728.	47.5
Phenol	5	0.047	0.001	0.012	0.0197
MBAS	5	0.5	0.1	0.18	0.178
BOD	1	9.0	9.0	9.0	-
COD	11	18.0	1.2	8.16	6.30
Total dissolved solids	12	1500.	1270.	1400.	62.9
Suspended solids	7	206.	4.0	47.7	72.6
Suspended volatile solids	6	108.	0.0	29.3	44.0
Lab pH	11	7.8	7.3	7.48	0.166
Turbidity (JTU)	7	44.0	0.7	10.0	15.3
Total carbonate (CO_3)	11	220.	190.	199.	8.39
Hardness ($CaCO_3$)	12	700.	450.	572.	58.4
Alkalinity ($CaCO_3$)	3	300.	162.	274.	96.9

Notes: Values in ppm unless specified
Well station WRRI 7

TABLE 6-5. MINIMUM AND MAXIMUM VALUES FOR WATER QUALITY PARAMETERS AT AMAX EAGLE BUTTE LEASE (all aquifers) (AMAX Coal Co., 1977a)

Constituent[a]	Minimum	Maximum
Silica	14	38
Calcium	79	375
Magnesium	20	420
Sodium	11	540
Potassium	2.8	44
Bicarbonate	150	1300
Carbonate	0	0
Sulfate	73	2800
Chloride	1.2	25
Fluoride	0.7	1.5
Nitrate	0.1	23
Boron	0	3.6
TDS	336	6600
Hardness (Ca + Mg)	240	2600
Specific conductance (mmhos)	507	9960
pH (units)	7.1	8.0

[a] Values in ppm unless specified otherwise

TABLE 6-6. SUMMARY OF WATER SAMPLING PROCEDURES DURING TESTS OF VARIOUS WELLS AT THE EAGLE BUTTE MINE (AMAX Coal Co., 1977a)

					Well site tests			
Well No.	Date	Aquifer	Elapsed pumping time (hrs)	Volume water produced (gal)	Specific conductance (mmhos)	pH	Temp (°C)	Final drawdown (ft)
BAN-1A	12/23/75	Wasatch?	3.42	41[a]	2800	8.0	11.7	30
BAN-3	8/19/75	Coal	0.63	285	3220	7.0	13.9	28.9
BAN-4	8/19/75	Coal	0.88	413	1800	7.2	15.5	57.9
BAN-5	8/19/75	Coal	0.65	133	1310	7.2	13.3	3.2
GN-6	12/18/75	Coal	0.80	57	1370	8.0	11.7	27.2
GN-7	1/6/75	Coal	4.50	567	1700	7.8	11.7	10.5
GN-8	1/7/75	Coal	0.65	532[b]	1750	7.4	11.1	∿0.1
GN-9	1/7/75	Ft. Union	10.33	1[c]	--	---	--	∿30
GNH-6B	8/19/75	Alluvium	1.33	112	--	7.4	15.0	--
Spring	8/18/75	Alluvium?	Artesian flow?	---	--	7.9	13.3	--

[a] Yellow color

[b] 1169 gallons pumped on 1/6/75

[c] Drilling fluid, not sampled

TABLE 6-7. RESULTS OF CHEMICAL ANALYSES OF GROUNDWATER FROM WASATCH WELLS (University of Wyoming, 1976)

Sample	Sample date	Lab[a]	Na^+ ppm	K^+ ppm	Ca^{++} ppm	Mg^{++} ppm	Alk[b] ppm	$SO_4=$ ppm	Cl^- ppm	SiO_2 ppm	TDS[c,d] ppm	pH
W-1	9/19/73	ARCO	318	-	121	82	454	610	84	9	(1680) 1610	7.4
W-2	3/31/73	ARCO	340	-	710	230	200	3100	47	8	(4635) 4340	7.7
W-2	2/26/75	UW	155	0.18	458	222	-	1900	14	-	3290[d]	7.5
W-3	10/4/73	ARCO	316	-	8	112	159	1160	11	5	(1770) 1206	7.4
W-4	10/3/73	ARCO	764	-	385	346	647	3200	113	21	(5476) 4823	6.6
W-4	12/3/73	UW	700	23	484	479	660	3456	183	20	6000	-
W-5	10/4/73	ARCO	510	-	197	46	157	1650	39	5	(2604) 2340	7.4
W-5	12/3/73	UW	452	90	186	55	161	1440	14	9	2408	-
W-6	10/4/73	ARCO	238	-	49	58	634	275	46	10	(1310) 1250	7.3
W-6	12/3/73	UW	245	7	19	22	465	238	28	11	1035	-
W-7	7/3/73	ARCO	200	-	47	49	785	52	53	13	1200	7.5
W-7	12/3/73	UW	269	8	34	25	804	35	37	13	1225	-
W-10	5/8/73	ARCO	420	-	100	66	433	990	34	13	(2056) 1890	7.6
W-10	2/26/74	UW	395	0.3	128	56	-	830	7	-	2094[d]	7.8
W-11	10/4/73	ARCO	281	-	33	24	805	51	46	10	(1250) 675	7.5
R-15A	12/3/73	UW	67	9	156	57	166	598	2	12	1067	-
Average			354	20	195	120	480	1220	47	11	2440	-
Minimum			67	0.18	8	22	159	50	2	5	1035	-
Maximum			764	90	710	479	805	3500	183	21	6000	-

[a] ARCO, Atlantic Richfield Co.; UW, University of Wyoming.

[b] Titration alkalinity reported as HCO-$_3$.

[c] Values in parentheses obtained by summing individual constituents.

[d] Alkalinity (calculated by difference) used to compute TDS.

TABLE 6-8. RESULTS OF CHEMICAL ANALYSES OF GROUNDWATER FROM ROLAND COAL SEAM WATERS (University of Wyoming, 1976)

Sample	Sample date	Lab[a]	Na^+ ppm	K^+ ppm	Ca^{++} ppm	Mg^{++} ppm	Alk[b] ppm	$SO_4^=$ ppm	Cl^- ppm	SiO_2 ppm	TDS[c,d] ppm	pH
R-1	9/19/73	ARCO	217	-	38	43	781	23	57	8	(1167) 774	7.3
R-2	10/4/73	ARCO	127	-	49	174	1049	410	31	9	(1848) 836	7.5
R-3	10/3/73	ARCO	87	-	283	132	201	1160	33	12	(1908) 2210	7.3
R-4	10/4/73	ARCO	214	-	45	21	750	58	27	8	(1120) 616	7.6
R-5	8/31/73	ARCO	165	-	55	49	790	<5	40	8	(1110) 680	7.2
R-6	8/31/73	ARCO	290	-	360	145	520	1530	40	13	(2430) 2660	7.0
R-7	10/4/73	ARCO	251	-	57	33	833	90	33	8	(1305) 777	7.5
R-8	7/3/73	ARCO	410	-	305	123	475	1670	25	6	(3010) 2810	7.3
R-8	9/11/73	ARCO	260	-	72	34	780	210	25	8	(1390) 1030	7.1
R-8	9/19/73	ARCO	235	-	43	27	802	11	59	8	(1185) 744	7.4
R-8	12/3/73	ARCO	249	8	26	27	600	180	13	11	1115	-
R-9	7/3/73	ARCO	400	-	103	49	875	550	30	11	(2020) 1790	7.1
R-9	12/3/73	UW	407	13	85	46	700	620	13	12	1896	-
R-10A	7/3/73	ARCO	65	-	380	145	585	1130	23	30	(2360) 2390	6.8
R-10D	12/3/73	UW	100	57	294	211	760	1152	2	18	2594	-
R-11	5/31/73	ARCO	380	-	82	35	1080	167	40	7	(1791) 1160	7.7
R-12A	6/15/73	ARCO	150	-	150	59	710	340	23	14	(1446) 1100	7.2
R-12C	12/3/73	UW	211	14	203	75	514	706	3	14	1740	-

---

[a] ARCO, Atlantic Richfield Co.; UW, University of Wyoming.

[b] Titration alkalinity reported as HCO-$_3$.

[c] Values in parentheses obtained by summing individual constituents.

[d] Alkalinity (calculated by difference) used to compute TDS.

(continued)

TABLE 6-8 (continued)

Sample	Sample date	Lab[a]	Na^+ ppm	K^+ ppm	Ca^{++} ppm	Mg^{++} ppm	Alk[b] ppm	$SO_4^=$ ppm	Cl^- ppm	SiO_2 ppm	TDS[c,d] ppm	pH
R-12D	10/4/73	ARCO	34	-	148	49	512	670	20	-	(1438) 1130	7.4
R-12E	7/3/73	ARCO	140	-	30	18	420	45	50	8	(711) 500	7.8
R-13	5/31/73	ARCO	490	-	230	91	1240	886	54	8	(3000) 2380	7.4
R-14	5/24/73	ARCO	375	-	119	20	872	380	60	22	(1848) 1440	7.7
R-14	2/26/74	UW	300	0.24	97	33	-	355	9	-	1600[d]	7.9
R-15B	5/31/73	ARCO	340	-	72	35	1040	160	40	10	(1700) 1170	7.6
R-17A	7/3/73	ARCO	264	-	200	73	530	850	40	10	(1970) 1765	7.0
R-151	7/27/73	ARCO	130	-	220	80	520	650	40	15	(1655) 1270	7.4
R-151	2/26/74	UW	90	0.11	203	83	-	560	8	-	1509[d]	6.9
R-153	7/27/73	ARCO	126	-	305	114	450	1050	30	17	(2090) 2050	7.9
R-153	12/3/73	UW	85	6	203	76	0	883	15	24	1292	-
R-154	8/31/73	ARCO	185	-	430	230	670	1750	40	20	(3325) 3100	7.2
R-156	10/9/73	ARCO	68	-	152	80	162	660	16	120	(1260) 954	7.3
R-156	12/3/73	UW	100	8	247	103	485	808	2	30	1783	-
Average			217	13	165	79	658	616	29	17	1770	-
Minimum			34	0.11	26	18	0	<5	2	4	711	-
Maximum			490	57	430	230	1240	1750	59	120	3325	-

[a] ARCO, Atlantic Richfield Co.; UW, University of Wyoming.

[b] Titration Alkalinity reported as HCO_3^-.

[c] Values in parentheses obtained by summing individual constituents.

[d] Alkalinity (calculated by difference) used to compute TDS.

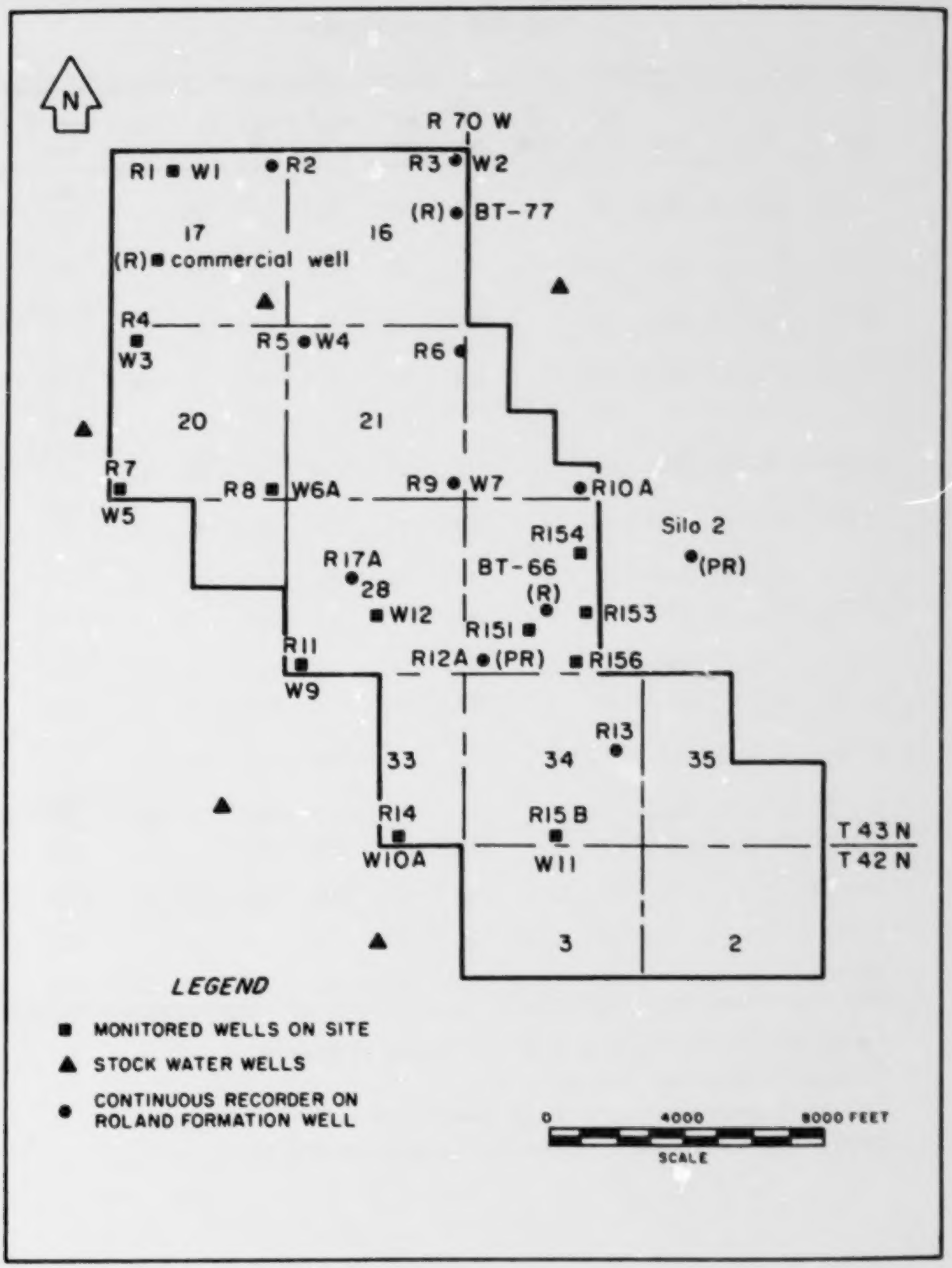

N
R 70 W
R1 ■ W1
● R2
R3 ● W2
(R) ● BT-77
17
16
(R) ■ commercial well
R4
W3
R5 ● W4
R6
20
21
R7
W5
R8 ■ W6A
R9 ● W7
● R10 A
Silo 2
●(PR)
R154
R17A
28
■ W12
BT-66
(R)
R151
R153
R11
W9
R12A ● (PR)
■ R156
R13
33
34
35
R14
W10A
R15 B
W11
T 43 N
T 42 N
3
2
LEGEND
■ MONITORED WELLS ON SITE
▲ STOCK WATER WELLS
● CONTINUOUS RECORDER ON ROLAND FORMATION WELL
0
4000
8000 FEET
SCALE

Figure 6-1. Groundwater gaging network at the Black Thunder Site (PR = Pre-Roland well; R = Roland well; W = Wasatch well) (University of Wyoming, 1976)

TABLE 6-9. SUMMARY OF WATER QUALITY AT BLACK THUNDER SITE SURFACE AND GROUNDWATER (values in ppm) (University of Wyoming, 1976)

Water quality characteristics	Range in Roland coal aquifer	Range in Wasatch aquifer
Major constituents		
Calcium	26-430	8-710
Magnesium	18-230	22-479
Sodium	34-490	67-764
Sulfate	<5-1750	50-3500
Chloride	2-59	2-183
Silicon dioxide	4-120	5-21
Potassium	0.11-57	0.18-90
Chemical and physical properties		
Total alkalinity	0-1240	159-805
Hardness (Ca + Mg)	-	-
pH (units)	6.9-7.9	6.6-7.8
Total dissolved solids (TDS)	711-3325	675-6000
Specific conductance (mmhos/cm)	-	-
Trace elements		
Arsenic	<5-<10	<5-<10
Beryllium	<1	<1
Cadmium	<0.02-5	<0.02-1.1
Copper	0.5-4.2	0.5-1.4
Lead	0.6-4.6	1-3.9
Mercury	<0.1-<0.5	<0.1-<0.5
Molybdenum	<1-2.6	<1-15
Selenium	<5	<5
Uranium	<1-3	<1-4

The ARCO sampling program has been more extensive and comprehensive than the programs at the other mines. As a result, a clear picture of groundwater quality in each aquifer has been presented. Wasatch water quality is highly variable. Water types are predominantly calcium or sodium sulfate, but two samples were of the sodium bicarbonate type. Roland coal seam waters have either calcium sulfate or sodium bicarbonate characters. In its Final Environmental Assessment (University of Wyoming, 1976), ARCO states that the waters in the eastern part of the lease are more often of the calcium sulfate type, and that as the waters move northwest, the character changes to sodium bicarbonate. ARCO speculates that exchange mechanisms cause this change in water type. However, surface chemical reactions probably are not the major contributor to the change. The highly concentrated calcium sulfate waters are at or near saturation, and precipitation of these elements as gypsum is probably occurring as the water moves to the west. ARCO has not presented chemical data on alluvial or scoria aquifer waters.

No groundwater quality data were published in the Carter North Rawhide Environmental Impact Statement (U.S. Geological Survey, 1974b). Four analyses were published in Carter's mining plan update (1977). Table 6-10 shows these analyses. Equivalent balances indicate that the ratio of cations to anions ranges from 0.97 to 1.01. Maximum and minimum data for selected constituents are given in Table 6-10.

TABLE 6-10. WATER QUALITY ANALYSES OF WATER WELLS ON THE RAWHIDE LEASE (Carter Oil Co., 1977)

	Sample			
Chemical analyses (ppm)	NRH-2 Roland	NRH-2 Smith	Clinker well	Main supply well
Calcium	545	114	504	7
Magnesium	209	54	183	4
Sodium	118	435	133	124
Carbonate	<0.1	<0.1	0	0
Bicarbonate	640	1,570	390	354
Sulfate	1,740	100	1,950	3
Chloride	74	65	12	12
Silicon dioxide	19	10	–	–
Hardness ($CaCO_3$)	2,200	502	2,010	34
Total solids	3,188	1,760	4,002	329
Evaporated solids	3,180	1,760	–	–
Suspended solids	8.5	<0.1	–	–
Volatile suspended solids	<0.1	<0.1	–	–
pH (units)	7.7	7.7	7.7	8.2
Specific conductance (micromhos/cc)	3,190	1,920	3,300	480
Turbidity (JTU)	15	2	–	3

TABLE 6-11. MINIMUM AND MAXIMUM VALUES AT CARTER OIL NORTH RAWHIDE LEASE FOR WATER QUALITY PARAMETERS (coal aquifers) (Carter Oil Co., 1977)

Constituent[a]	Minimum	Maximum
Silica	10	19
Calcium	7	545
Magnesium	4	209
Sodium	118	435
Bicarbonate	354	1,570
Carbonate	0	0
Sulfate	3	1,740
Chloride	12	74
Hardness as $CaCO_3$	34	2,200
pH (units)	7.7	8.2

[a] In ppm except as shown for pH

These data are not definitive, yet they indicate that the coal waters can have calcium sulfate or sodium bicarbonate characters. Clinker water is generally regarded to be of poor quality, and this feature is supported by the Carter analysis. Fort Union deep wells produce waters with good quality characteristics. The low TDS figure, coupled with the softness of the water, indicate that the best quality water on the Carter lease can be found in deep wells.

Chemical data for groundwater on or near the Kerr-McGee Jacobs Ranch lease have been continuously collected since as early as 1966. Reports included in Kerr-McGee's Jacobs Ranch Mining Plan Update (1977) include data from samples analyzed by Kerr-McGee and by the University of Wyoming. Equivalent balances on some of the analyses indicated that cation-anion ratios ranged near 1.00. Representative analyses are given in Tables 6-12 and 6-13.

Some of the waters analyzed may have been composite samples from both the Wasatch and coal aquifers. Completion data for the KM series of wells were not included in the Mining Plan Update (1977). With the exception of KM-3, all of the wells at the Jacobs Ranch mine area have calcium sulfate waters. No analyses were presented for alluvial or scoria wells.

In its Mining Plan Update (1977), Kerr-McGee states that although TDS values are high, salt tolerant crops should survive if irrigated with Jacobs Ranch groundwater. Sodium adsorption ratios are expectedly low, and boron concentrations are all less than 1 ppm. Selenium, cadmium, and lead concentrations exceed EPA drinking water standards in the following: KM-3, 4, 5, 11, 12 wells.

TABLE 6-12. CHEMICAL ANALYSIS OF WATER FROM WELLS WITHIN 6 MILES OF PROPERTY BOUNDARY OF PROPOSED KERR-McGEE JACOBS RANCH COAL MINE (Hodson, 1971)

Location/constituent	Fort Union Formation		Wasatch Formation			
Well location[a]	42N069W07BAC 1	43N069W19AB 1	42N070W05DDD 1	43N070W11DA 1	44N070W28CBC 1	44N071W10DD 1
Well depth (ft)	120	170	233	455	261	124
Date of sample	07-08-68	08-07-68	07-09-68	08-07-68	08-07-68	07-08-68
Temperature (deg C)	–	11.0	12.0	11.0	11.0	11.0
Silica (SiO_2)(ppm)	7.7	5.6	37	28.0	8.9	14
Total iron (Fe)(ppm)	0.550	0.490	1.300	0.030	0.440	0.030
Calcium (Ca)(ppm)	32	61	414	244	40	299
Magnesium (Mg)(ppm)	17	30	919	66	9.7	110
Sodium (Na)(ppm)	161	385	720	83	221	74
Potassium (K)(ppm)	7.8	9.2	6.8	18	5.2	7.0
Bicarbonate (HCO_3)(ppm)	370	300	254	227	345	242
Carbonate (CO_3)(ppm)	13	16	0	0	10	0
Sulfate (SO_4)(ppm)	185	828	5940	885	306	1080
Chloride (Cl)(ppm)	4.4	4.0	35	2.8	13	5.8
Fluoride (F)(ppm)	0.4	0.6	1.0	0.9	1.0	0.4
Nitrate (NO_3)(ppm)	0.9	0.3	0.2	1.6	0.2	1.9
Boron (B)(ppm)	50	10	60	–	10	60
Dissolved solids (residue at 180° C)	610	1450	8620	1450	792	1860
Dissolved solids (sum of constituents)	613	1490	8200	1440	785	1710
Hardness (Ca,Mg)(ppm)	149	276	4810	880	140	1200
Non-carbonate hardness (ppm)	–	–	–	–	–	–
Specific conductance (mmhos)	951	2080	7660	1720	1180	2040
pH (units)	8.4	8.5	8.1	8.1	8.5	7.9

[a] Well location, 42N069W07BAC 1 = Township 42 North; Range 69 West; section F; quarter, quarter, quarter section BAC respectively.

TABLE 6-13. LABORATORY ANALYSIS OF WATER FROM STOCK AND DOMESTIC WELLS DRILLED PRIOR TO GRANTING OF LEASE TO KERR-McGEE (Kerr-McGee Coal Corp., 1977)

Location/date/ constituent	Well				
	KM #11		KM #4	KM #9	KM #1
Location	NE, SE	SE, NW	SE	SE	NE
Section	11	19	33	32	29
T (N)	43	43	44	44	44
R (W)	70	69	70	70	70
Date sampled	8-7-68	8-7-68	2-?-75	2-?-75	2-?-75
Constituents (ppm)					
pH (units)	8.1	8.5	7.3	7.4	7.7
Temp (° C)	11.0	11.0	-	-	-
TDS	1440	1490	4072	1152	460
TSS	-	-	5	11	86
Hardness ($CaCO_3$)	880	276	1410	360	90
Elect. Cond. (mmhos)	1720	2080	-	-	-
Ca	244	61	-	-	-
Mg	66	30	-	-	-
Na	83	385	-	-	-
K	18	9.2	-	-	-
As	-	-	0.005	0.005	0.005
B	0.570	0.010	0.04	0.1	0.01
Pb	0.570	0.010	0.04	0.03	0.005
Si	28	5.6	-	-	-
Zn	-	-	0.4	0.6	0.05
Mn	-	-	0.3	0.09	0.01
Ni	-	-	0.04	0.1	0.005
Cr	-	-	0.04	0.01	0.001
Cd	-	-	0.01	0.003	0.001
Hg	-	-	0.001	0.001	0.001
Cu	-	-	0.04	0.06	0.05
Fe (total)	0.030	0.490	0.1	0.6	0.05
CO_3	0	16	-	-	-
HCO_3	227	300	-	-	-
SO_4	885	828	-	-	-
Cl	2.8	4.0	-	-	-
NO_3	1.6	0.3	-	-	-
F	0.9	0.6	-	-	-

TEMPO monitoring efforts will be aided by the water quality samples that have been analyzed at Jacobs Ranch. Information on well-drilling techniques, well completions, and sampling and analytical procedures will aid in evaluating the usefulness of the previously collected data.

Although Sun Oil Cordero has been shipping coal since March 1977, its groundwater monitoring program is not well developed. In the Cordero Mining Co. Mining Plan Update (1976), officials indicated the existence of only four groundwater quality monitoring wells. These include three water wells and one stock well. All are Wasatch Formation wells. Groundwater quality values for these wells are shown on Tables 6-14 and 6-15.

Cordero reported that these samples show stable values, and that they are usable data. However, the stock well sample was not a pumped sample, and no field sampling techniques were discussed. Also, the Hayden well is less than 1,000 feet from a major tributary to the Belle Fourche River. The low quantity of dissolved solids in this water is probably due to hydraulic connection with low TDS surface water.

Cordero has reportedly designed a new monitoring plan (Tim Richmond, Cordero Mining Co., oral communication, 1977). This plan is not yet available, but when it is acquired, further analysis can be undertaken.

In the Wyodak Resource Development Corp. Mining Plan Update (1977), chemical analyses of water obtained from four wells on the lease were presented. Two of the wells are located near the ash pit, one was at a coal completion monitoring well near the southern end of Wyodak's property, and the fourth well supplies domestic water from deep Fort Union aquifers. Analytical problems are indicated by cation-anion ratios which ranged from 0.75 to 5.5 for the analyses presented. Table 6-16 presents maximum and minimum values of dissolved constituents in Wyodak water.

These sparse data presented by Wyodak allow little interpretation. The analyses are consistent with regional trends, in that the shallow waters are soft and potable. Background quality monitoring must be undertaken near pollution source areas so that future aquifer degradations can be recognized.

MUNICIPAL

City of Gillette Existing Groundwater Quality

The City of Gillette uses water from the Wasatch Formation, the Fort Union Formation, and the Fox Hills Formation. The Wasatch wells are considered hard water wells, and the Fort Union wells soft water wells. The Fox Hills waters are of marginal quality, with high TDS, high fluoride concentrations, and some associated hydrogen sulfide gas being the problem parameters. The waters from all three systems are blended to produce a potable municipal supply. Tables 6-17 and 6-18 summarize analyses of the City wells, as performed by Nelson et al. (1976).

TABLE 6-14. GROUNDWATER QUALITY, HAYDEN RESIDENCE, SUN OIL CORDERO LEASE (Cordero Mining Co., 1976)

	Date			
Constituent (ppm)	Sep 3, 1974	Nov 25, 1974	Feb 9, 1975	May 22, 1975
Total dissolved solids	328	360	390	354
Suspended solids	-	6	-	-
Hardness	44	45	47	85
Bicarbonate-as HCO_3	385	377	403	506
Carbonate-as CO_3	<1	0	0	0
Sulfate	<5	3	<1	4
Chloride	7	9	10	18
Nitrate	1.5	2.9	1.6	1.5
Fluoride	1.5	1.0	1.9	1.1
Sodium	118	133	150	122
Calcium	-	10	-	-
Iron	-	0.24	-	0.05
Lithium	-	0.01	-	0.04
Arsenic	-	<0.01	-	0.00
Selenium	-	0.011	-	0.00
Boron	-	0.11	-	0.00
Zinc	-	0.14	-	0.03
Mercury	-	<0.5	-	0.000
Cadmium	-	<5	-	0
Copper	-	-	-	0.00
Lead	-	-	-	0.00
Chromium	-	-	-	0.00
Molybdenum	-	-	-	0.00
Nickel	-	-	-	0.00
Aluminum	-	-	-	0.0
pH-field (units)	-	-	7.58	-
-lab (units)	7.9	7.8	8.1	-
Alkalinity as $CaCO_3$	-	309	-	-

TABLE 6-15. GROUNDWATER QUALITY, WELL NUMBER 11, SUN OIL CORDERO LEASE (Cordero Mining Co., 1976)

Constituent (ppm)	Date		
	Nov 25, 1974	Feb 9, 1975	May 22, 1975
Total dissolved solids	(a)	2000	2160
Hardness	(a)	920	925
Bicarbonate-as HCO_3	412	770	1010
-as $CaCO_3$	-	-	-
Carbonate-as CO_3	0	0	0
-as $CaCO_3$	-	-	-
Sulfate	900	910	959
Chloride	8	12	19
Nitrate	13.2	0.90	0.7
Fluoride	0.58	0.53	0.48
Sodium	415	440	321
Calcium	56	-	-
Iron	0.028	-	0.03
Lithium	-	-	0.10
Arsenic	-	-	0.00
Selenium	-	-	0.00
Boron	0.14	-	0.01
Zinc	-	-	0.00
Mercury	-	-	0.000
Cadmium	-	-	0.00
Copper	-	-	0.00
Lead	-	-	0.00
Chromium	-	-	0.00
Molybdenum	-	-	0.00
Nickel	-	-	0.04
Aluminum	-	-	0.00
pH-field (units)	-	7.6	-
-lab (units)	8.1	7.9	-
Alkalinity as $CaCO_3$	337	-	-

[a] Sample not sufficient to analyze.

TABLE 6-16. MINIMUM AND MAXIMUM VALUES FOR WYODAK MINE WATER QUALITY PARAMETERS[a] (Wyodak Resource Development Corp., 1977)

Constituent[b]	Minimum	Maximum
Calcium	179	599
Magnesium	47	327
Sodium	220	330
Potassium	7	33
Bicarbonate	163	396
Carbonate	0	6
Sulfate	110	3825
Chloride	2	110
Nitrate	0	2.7
TDS	1714	4652
pH (units)	7.3	8.5

[a] Based on only four samples available.

[b] Expressed in ppm except for pH.

TABLE 6-17. WATER QUALITY ANALYSIS SUMMARY (Nelson et al., 1976)

Source	Arsenic allowable 0.05	Barium allowable 1.0	Cadmium allowable 0.01	Chromium allowable 0.05	Lead allowable 0.05	Mercury allowable 0.002	Nitrate as (N) allowable 10.0	Selenium allowable 0.01	Silver allowable 0.05	Fluoride allowable (1.8)
Lance Fox Hills Well No. 2	ND[a] (0.01)	ND (0.05)	ND (0.01)	ND (0.01)	ND (0.05)	ND (0.001)	0.98	ND (0.01)	ND (0.01)	11.2
Wasatch Well No. 17	ND (0.01)	ND (0.05)	ND (0.01)	ND (0.01)	ND (0.05)	ND (0.001)	0.19	ND (0.01)	ND (0.01)	ND (0.1)
Fort Union Well No. 6	ND (0.01)	ND (0.05)	ND (0.01)	ND (0.01)	ND (0.05)	ND (0.001)	0.11	ND (0.01)	ND (0.01)	1.4
Pre-treatment plant product	ND (0.01)	ND (0.05)	ND (0.01)	ND (0.01)	ND (0.05)	ND (0.001)	0.94	ND (0.01)	ND (0.01)	3.9
E.D. plant product	ND (0.01)	ND (0.05)	ND (0.01)	ND (0.01)	ND (0.05)	ND (0.001)	0.23	ND (0.01)	ND (0.01)	1.0
City tap water	ND (0.01)	ND (0.05)	ND (0.01)	ND (0.01)	ND (0.05)	ND (0.001)	0.93	ND (0.01)	ND (0.01)	2.6

[a] ND = Not detected at level indicated; Example = ND(0.01) = Not detected at level of 0.01 (ppm)

Note: Allowable limits indicated are mandatory as set by National interim primary drinking water regulations.

TABLE 6-18. WATER QUALITY ANALYSIS SUMMARY—GILLETTE, WYOMING, WATER SUPPLY, 1976 (Nelson et al., 1976)

Source	gpm	K	Ca	Mg	SO_4	Cl	Na	CO_3	TDS	NaCl	pH	Conductivity	Hardness $CaCO_3$	Alkalinity $CaCO_3$
Fox Hills No. 1	56	6	40	24	256	64	483	1098	1414	1063	7.8	1960	199	901
Fox Hills No. 2	210	4	trace	trace	8	56	489	1074	1146	919	8.2	1700	trace	981
Fox Hills No. 3	340	5	3	trace	2	36	358	903	849	647	8.1	1242	7.50	740
H-1	41	7	161	82	412	16	108	647	1105	829	7.1	--	740	-
H-7	41	10	321	188	910	170	18	537	1881	1479	7.4	2000	1574	441
H-8														
H-10	48	7	321	148	1320	28	144	390	2160	1545	7.3	--	1410	-
H-12	56	14	291	127	1200	8	34	98	1722	1213	6.9	--	1248	-
H-13	82	18	602	182	1920	16	72	500	3056	2137	7.7	2810	2250	410
H-14	52													
H-15	82	12	552	255	2050	24	58	488	3191	2285	7.1	2775	2425	400
H-16	52	13	432	145	1300	36	89	586	2304	1647	7.4	2225	1674	480
H-17	96	14	502	170	1650	28	90	500	2700	1909	7.4	2350	1951	410
H-18	56													
H-19	59	11	40	248	1620	44	69	537	2658	1957	7.4	2625	2022	440
H-20	41	8	221	18	460	44	333	1000	1577	1131	8.0	2083	625	820
H-21	56	14	462	170	1550	16	72	476	2518	1784	7.4	2450	1851	415
H-22	41													
H-23	37													
H-24	82	17	552	194	1920	20	114	512	3069	2162	7.6	2950	2174	420
H-25	74	15	562	200	2050	20	95	354	3116	2184	7.7	2985	2224	290
H-26	85	11	311	109	1150	12	117	342	1878	1321	7.6	2000	1224	280
H-27	59	7	341	145	1250	28	52	281	1961	1402	7.3	1925	1447	231
S-2	65	6	6	2	3	12	119	329	310	237	7.3	435	23.0	270
SH-3	83	9	462	94	1180	16	14	403	1973	1365	7.3	2060	1539	331
S-4	65	7	20	30	10	28	142	537	501	406	7.5	775	174	441
S-5	75	5	15	12	12	16	102	342	330	260	7.5	476	87	281
S-6	50	6	15	12	8	16	132	427	399	312	7.5	585	87	350
S-7	55	5	15	6	8	20	105	317	315	246	7.5	410	62	260
City water at tap		9	131	70	565	32	164	427	1181	867	7.8	1550	615	350
Calculated composite hard water	1560	9.5	305	158	920	36	220	666	1888	1369	7.7	1793	1248	589
Sampled composite hard water		8	216	103	668	44	122	586	1450	1077	7.5	1950	963	481

Notes:
1. All figures are in ppm with the exception of pH and conductivity. Conductivity is in mmhos/cm^3.
2. TDS = Total dissolved solids.
3. NaCl = Salt equivalent of TDS.
4. Calculated composite hard water includes weighted contribution from all hard water wells.
5. Sampled composite hard water represents a sample taken from raw water tank.
6. Soft water well waters bypass raw water tank and flow directly into city water system.

COMPOSITE =

$$\frac{\left[\Sigma'_n(\mathrm{GPM}_n)(\mathrm{PROPERTY}_n)\right]}{\Sigma'_n(\mathrm{GPM})}$$

The Wasatch waters (prefix H) are generally nonpotable. Extremely high sulfate concentrations make these waters particularly undesirable. Some hydrogen sulfide gas is associated with the Wasatch waters. TDS values range from 830 to 2,300 ppm, pH values range from 6.9 to 8.0, and the Wasatch waters are virtually all of the calcium sulfate type.

The City of Gillette has no wells which draw water from fractured coal seams. Therefore, the contribution from shallow aquifers, as defined in this study, is the hard water Wasatch wells. Table 6-18 also includes data from Fox Hills and deep Fort Union wells (prefix S). The deep Fort Union wells yield the best product in the project area. These high-quality sodium bicarbonate waters are being developed more extensively as the City of Gillette expands it drilling program.

SECTION 7

INFILTRATION POTENTIAL

A necessary step in estimating the impact of the pollutants associated with the various potential sources is to determine the volume of water leaving the source and passing through the vadose zone into the zone of saturation. This volume will vary with the method of waste disposal used, e.g., disposal at the land surface, burial in the vadose zone, or burial below the water table, and the infiltration characteristics of the soil.

Based on the limited source monitoring currently being carried out in the project area collectively by the mines, the City of Gillette, and various State and Federal agencies, only exemplary estimates of infiltration potential for a few select sources can be made. These sources fall under three major categories: coal strip mining, coal conversion, and municipal.

COAL STRIP MINING

Sufficient information is available in the project area to provide some estimate of the infiltration potential of pit discharge and spoils materials.

Pit Discharge (Active Mining Area Source)

As discussed previously in Section 2 (Potential Sources of Pollution and Methods of Disposal), the primary methods of disposal of pit discharge and their hydrologic source classifications are:

- Dust control – diffuse
- Irrigation of reclaimed spoils – diffuse
- Discharge to surface water and subsequent percolation – line.

In the case of discharge to surface water, holding ponds are commonly used to retain the pit discharge prior to release. These holding ponds thus comprise a potential point source of groundwater pollution.

Pit discharge is used for dust control primarily in the months when precipitation is low and the land surface is relatively dry. This water is applied to haul roads in the pit, haul roads between the pit and the coal storage silos, and to other unpaved roads around the plant. Such roads are commonly built on natural soil or disturbed overburden, and sometimes on the coal itself in the pit. Most of this water is applied during periods of maximum potential evapotranspiration. The surfaces to which the water is applied are relatively compacted due to heavy equipment traffic. Thus, virtually none of the applied water would be expected to infiltrate and percolate beneath the surficial materials, but would largely be lost to evapotranspiration. However, pollutant constituents in the applied water are largely retained in the surficial materials. These constituents could later be leached to groundwater as a result of excessive watering of the roads or as a result of rainfall causing runoff to carry the potential pollutants into the ditches.

The infiltration potential of pit discharge used for irrigation of reclaimed spoils is discussed under Spoils (Reclaimed Area Source).

The primary method of disposal of pit discharge in the winter, when use of water for dust control is minimal or unnecessary, is to streams near the mines. This water usually mixes with other surface water which is present in the winter. As streamflow, there is potential for percolation, particularly in areas downgradient from the mines. Streamflow can percolate to aquifers whose water levels are below the channel bottom. This is a potential line source of pollution in the hydrologic context and may be from several to tens of miles long, depending on the streamflow and infiltration characteristics. Since much pit discharge water is disposed of in winter months when evapotranspiration rates are low, less opportunity exists for disposal by evapotranspiration.

Holding ponds for pit discharge may overlie native materials, such as alluvium beneath a floodplain, or disturbed materials such as spoils. The amount of infiltration depends to a large extent on the permeability of the underlying materials. In general, the future locations of holding ponds and the underlying materials are poorly known for most mines and, thus, their infiltration potential is also poorly known. Better knowledge could be gained by the careful measurement of flow volumes for pit discharge and the disposition of pit discharge. This, in combination with knowledge of precipitation and evapotranspiration rates, would allow water budget calculations to determine wastewater loading and infiltration for each method of disposal.

Spoils (Reclaimed Area Source)

Four primary sources of water may eventually contact the spoils. These sources can be grouped into point, line, and diffuse in the hydrologic context. The sources are:

- Precipitation or applied irrigation water – diffuse
- Streamflow – line
- Ponded water above spoils – point
- Groundwater – diffuse.

Little precipitation is expected to percolate past the topsoil due to the relatively high potential evapotranspiration rates as compared to the precipitation rate. As discussed under the modified hydrogeology portion of Section 5 (Hydrogeologic Framework), the presence of free lime in undisturbed soils suggests that under natural conditions little or no precipitation infiltrates past the topsoil.

The spoils will be dressed with topsoil or equivalent. Parts of the spoils will contain a high percentage of broken and pulverized shale that decomposes rapidly. Such spoils will generally have a high clay content and are expected to have low permeability. Other parts of the spoils will contain broken and pulverized sandstone and alluvium and may be more permeable. The structure of the soil used for surface dressing will be destroyed in handling and this material will generally have a higher infiltration capacity than the underlying spoils.

However, after settlement, the surface dressing will probably have a lower infiltration capacity than the natural soils. Thus, it is unlikely that infiltrating water from precipitation will percolate past the topsoil on areas other than those that receive surface runoff.

Water availability will be a limiting factor in irrigating spoils during the first several years of reclamation. The relatively low aquifer transmissivities and well yields limit large scale water applications for irrigation. However, there is some potential for downward percolation of return flow from irrigation, depending on the amount of water applied compared to the evapotranspiration. Measurement of water application will enable estimates to be made of potential infiltration by the water budget method.

Many mining plans call for removal of coal beneath present-day floodplains. During mining, the stream is temporarily diverted around the active pit. After mining, when the spoils are in place, the streams are to be reestablished to simulate natural conditions. In this situation, spoils materials will be returned in place of natural alluvium beneath the stream channels. Geomorphic processes will then act to reestablish a hydraulic equilibrium. For example, alluvium may be carried into the area from upgradient lands, or some spoils. This will depend on the permeability of the spoils and top dressing, the possible presence of organic deposits in the channel infiltration, and the turbidity of the flowing water. Although the spoils will probably have a lower infiltration capacity than the alluvium, seepage from streamflow could be a major source of water coming into contact with the spoils. In this case, water available for infiltration depends on streamflow. The amount of infiltration through the channel bottom depends not only on the subsurface materials, but on the hydraulic head distribution. If groundwater levels are higher than the channel bottom, little or no infiltration will occur. Present data indicate that the natural channels in and near the mine leases are both gaining and losing, depending on the area and reach of the stream. The same situation may also prevail after the alluvium is removed.

If water is temporarily ponded above spoils, then a point source of groundwater pollution may result from leaching. In this case, the amount of water available for infiltration can greatly exceed the evapotranspiration rate. If groundwater levels are of sufficient depth, then percolation of the water past the topsoil can readily occur. The infiltration rate will depend on permeability of the spoils, the amount of organic deposits in the pond bottom due to biologic activity, and turbidity and temperature of the stored water. This particular source would probably be of limited duration for holding ponds, but if large bodies of standing water are formed on the dressed spoils due to topographic conditions, a source of long-term duration could be established.

In the case of groundwater migrating laterally through the spoils, the topsoil and vadose zone are bypassed, and there is no need to discuss infiltration potential from the land surface.

COAL CONVERSION

Potential Pollution Sources

Of the three important types of coal conversion anticipated to be implemented in the project area – steam electric, gasification, and liquification – only steam electric currently is operating at a level where significant impacts are expected.

Steam Electric Power Plant –

The existing and planned power plants at Wyodak will generate wastes from a number of sources. Presently, fly ash and some other wastes are discharged to a slurry pond in the North Pit. Future plans call for disposal of virtually all wastes from the power plant in the two pits at the Wyodak mine. The wastes to be disposed of are fly ash as solid fill in the pits, and liquids and other wastes in a pond in the North Pit.

Fly ash in the solid form could be emplaced at any depth in the pit. This disposal method is similar to that for spoils, in that some material could be considerably above groundwater, but still be subject to leaching.

A number of types of liquid wastes, including sewage effluent, apparently will be disposed of in the existing pond in the North Pit and may constitute an abundant source of water for leaching. Although an extensive clay bed reportedly underlies the coal at Wyodak, the infiltration potential of wastes from this pond is poorly known. A water budget analysis could be made if the volume of flow and solid fly ash were known.

MUNICIPAL SOURCES

The City of Gillette is the principal municipality in the project area. Three primary potential sources of groundwater pollution are associated with the City: the landfill, the sewage treatment plant, and the water treatment plant. A matter of regional concern is the potential impact of the coal strip mining on the City's water-well field. Currently, only limited information is available on the first three potential sources, and insufficient information is available to discuss the impact of mining on the well field.

Landfill

Sources located at the landfill site include: a metal disposal area, oil waste disposal area, dead animal pit, garbage trenches, oily waste and septic tank pumpage sites, tire disposal area, and a covered dump. Except for the garbage trenches, these pits and disposal areas terminate within overburden overlying a shallow coal seam. The garbage trench is constructed within the coal bed.

Metal Disposal Area –

The metal disposal area serves as a repository of refrigerators, old cars, metal drums, other discarded metals, and tires. These solid wastes are discarded on the land surface. Consequently, infiltration occurs across the indigenous soil surface. Infiltration is probably optimal because of the minimal disturbance of the soil surface.

Oily Waste Disposal Area –

Wastes disposed of in this area include primarily petroleum byproducts, and possibly some hazardous substances. Infiltration may be inhibited by the movement of sludge sediment and fines into the pores and cracks of the overburden. In addition, certain organic fluids may preclude capillary uptake.

Dead Animal Pit –

Infiltration beneath the dead animal pit is probably similar to that for undisturbed materials, except possibly for slight clogging by organics.

Garbage Disposal Site –

The garbage disposal trench infiltrates into the fractured coal seam. The surface of the seam may be disturbed by the operation of heavy equipment, impeding intake rates. Surface runoff into the trench may carry down fine sediments which would also tend to seal off the surface. The penetration of landfill leachate with high concentrations of calcium and sulfate might lead to the formation of gypsum deposits within seam fractures, again reducing infiltration. Precipitation of limonite $[Fe(OH)_2]$ would have a similar effect. The degree of infiltration reduction by these mechanisms may depend greatly on the size of fracture openings.

Pits for Oily Waste and Septic Tank Pumpage –

Infiltration characteristics are similar to those of the oily wastes disposed of in the same area and may restrict infiltration.

Covered Dump –

Surface infiltration into the covered dump may be similar to that for native material. Movement of pollutants from the base of the dump into the native vadose zone is governed, to some extent, by processes similar to those discussed for the active landfill.

Sewage Treatment Plant

Potential sources of groundwater contamination associated with wastewater treatment in Gillette include: (1) treatment plant facilities; (2) an oxidation pond; (3) a sludge disposal pond; and (4) Donkey Creek.

Treatment Plant Facilities—

Treatment plant facilities include aeration, secondary clarifiers, and aerobic digestion tanks.

Discussion with wastewater management officials for the City indicate that the aeration, clarifier, and digestion tanks may leak directly into the shallow groundwater system at the plant site. No data are available, however, on the magnitude of seepage.

Oxidation Pond—

Wastewater entering the "oxidation" pond probably has received minimal treatment in the wastewater treatment plant. Additional treatment in the pond probably occurs under anaerobic rather than aerobic conditions.

Infiltration from the pond may be minimal because of the penetration of benthic materials into the pores of the underlying soils — an effect observed in established ponds (Deming, 1963). An exact value will necessitate a water balance study (Todd et al., 1976).

Sludge Disposal Pond—

The infiltration potential of the sludge pond will be restricted by the movement of organics and fine sediments into the pores underlying vadose zone materials. In fact, the infiltration rate may be essentially zero.

Donkey Creek—

Wastewater discharged from the oxidation pond enters Donkey Creek, essentially a line source of potential groundwater contamination. The quality of wastewater will change somewhat during flow in the creek. For example, nitrates may increase because of aeration due to algal activity, wind action, etc. In addition, periodic discharge events resulting from flash floods or snowmelt may dilute pollutants.

Infiltration into the Donkey Creek streambed will generally decrease over time because of clogging of the channel deposits with organics and fines. However, periodic discharge events may scour the channel and temporarily increase intake rates. In addition to infiltration, another factor to consider is the consumption of water from the vadose zone by riparian vegetation along the channel. The amount of recharge into the saturated zone will consequently be reduced during the growing season of such vegetation. Evapotranspirative losses may also occur directly from the shallow groundwater system.

Water Treatment Plant

Water treatment facilities for the City of Gillette include a degasifier, a raw water storage tank, a lime softening plant, and an electrodialysis plant (Nelson et al., 1976). Wastewater from the lime softening plant and electrodialysis plant is discharged directly into the Stone Pile Creek or into a nearby hand-dug brine disposal well. Most of the wastewater goes into Stone Pile Creek. The disposal well is filled with filter sand and occasionally refilled as it subsides.

Brine from the electrodialysis plant probably contains excessively high concentrations of major chemical constituents together with trace contaminants. Organics and microorganisms probably are not present in significant quantities. Sulfate is the principal contaminant in wastewater from the lime softening process.

Wastewater discharged into the disposal well probably bypasses the entire vadose zone and enters directly into a shallow aquifer. "Infiltration," thus, refers to seepage of wastes out of the well into the aquifer. In effect, the well functions as a type of recharge well. Intake rates of such wells are affected mainly by entrained air, sediment, precipitation of salts, and microbial activity. Intake rates in the brine disposal well are probably affected by sediment, salt precipitation, and entrained air.

Infiltration of wastewater in Stone Pile Creek may be decreased by the precipitation of salt in the stream channel; by clogging resulting from microbial activity; or by sedimentation. Periodic discharge events in the Creek from snowmelt or flash floods may scour the channel and improve intake rates. Some water loss may occur in the channel and underlying alluvium by evapotranspiration. Such losses may increase salt concentration of infiltrating wastewater.

SECTION 8

POLLUTANT MOBILITY IN THE VADOSE ZONE

This section discusses the movement of pollutants which have infiltrated the vadose zone. The pollution sources discussed fall under the major categories of coal strip mining, coal conversion, and municipal.

COAL STRIP MINING

The primary methods of disposing of strip mining pit discharge water are to use the water for dust control on mining roads during the dry season, discharging surplus water to streambeds during the wet season, and using the water for irrigation of reclaimed spoils. Pollutant mobility of water infiltrating into the vadose zone from these uses is discussed in this subsection in terms of water movement and pollutant transport and attenuation mechanisms.

Pit Discharge (Active Mining Area Source)

When using pit discharge water for dust control, the amount applied is not sufficient to mobilize any pollutants in the water downward from the surface. However, road wetting in a pit can result in pollutants that remain at the bottom of the pit or are later emplaced in subsurface spoils, enhancing their potential for groundwater pollution. The pollutants will be comprised of those that are indigenous to the native groundwater plus any added by mining operations.

Discharge of pit water to the surface will usually be to an alluvial channel where the vadose zone is typically very thin. In some future situations, the discharge could be to a stream overlying spoils in a reclaimed area. Shallow groundwater levels may prevent percolation in the channel of streamflow, or mixing with other surface water may attenuate pollutants substantially before reaching a point downstream where percolation or evapotranspiration does occur. Such a determination can be made only by accurate measurement of the rate of waste discharge and the rate of flow upstream and downstream from the discharge point.

Pollutant attenuation mechanisms in the chemical sense are poorly known because the lithology of the alluvium has not been adequately established. Little pollutant attenuation may occur in sandy areas, while substantial pollutant attenuation may occur in clay areas. Some pollutants could be removed from the discharge area by streamflow that does not percolate and become concentrated downstream. Alternatively, the pollutants could migrate downward near the point of discharge and concentrate in local aquifers.

Spoils (Reclaimed Area Source)

Several sources of water may enter the vadose zone in the spoils. These include return flow of water used for irrigation during reclamation of spoils, streamflow percolation in former floodplain areas, and seepage from holding ponds constructed on the spoils.

Mann (1976) discusses hydrologic interactions for wastewater in the vadose zone of arid regions. The vertical distribution of materials comprising spoils will affect downward movement of water in the vadose zone. Poor topsoils, disturbed overburden, waste coal, shale interlayers, buried refuse, and other materials will be somewhat haphazardly emplaced as spoils. Perching layers may be formed and result in saturated conditions and lateral movement of percolating water in the vadose zone. Under present conditions, water flow in the vadose zone is apparently largely through fractured consolidated rocks. Because the spoils are largely comprised of broken up rocks, the modified flow may be through a medium more similar to granular, porous media and this unconsolidated material will be more subject to leaching as water passes through it. Virtually nothing is presently known about the hydrologic characteristics of the existing natural vadose zones or those that will exist after the spoils are emplaced. However, the characteristic depth to water is likely to be 100 to 200 feet.

Little excess irrigation water is expected to percolate past the topsoil during reclamation. However, the volume of applied water can be measured to determine potential percolation past the topsoils, and the water budget can be calculated to determine if the water application, hydrologic characteristics of the spoils and dressing material, and climatic factors at a given location appear to result in a net excess.

Leaching potential from streamflow percolation may be substantial in the former floodplain areas after emplacement of spoils. Accurate measurements of flow at stream-gaging stations along certain reaches of these areas can be used to determine seepage losses. Depending upon the water table depth, virtually all of the water passing through a stream channel could be absorbed. However, groundwater beneath the floodplains could be ultimately consumed by evapotranspiration. Perching layers above the water table could result in horizontal movement of the recharged water some distance away from the stream channel.

Substantial volumes of water may seep from holding ponds constructed on spoils to the water table. Perching layers above the water table may spread recharge water horizontally and increase the impacted groundwater area beyond that of the surface source.

Although slightly different combinations of pollutants may be introduced by the different sources of water, vadose zone pollutants derived from spoils will be similar regardless of the source of water. Most of the additional pollutants that will be in pit discharge water used for irrigation are covered by the parameters of concern for the spoils. Thus the following discussion generally applies to all three sources of water applied to the spoils. Potential pollutants include inorganic chemical, organic chemical, and radiological types.

Potential Mining and Reclamation Pollutants

Major inorganic chemical groundwater pollutant constituents that can enter the vadose zone are calcium, magnesium, sodium, potassium, carbonates, chlorides, sulfates, boron, fluorides, iron, manganese, nitrogen oxides, and phosphorous oxides. Inorganic chemical trace elements are barium, chromium, copper, lead, lithium, nickel, strontium, vanadium, zinc, zirconium, arsenic, cobalt, cadmium, mercury, beryllium, selenium, molybdenum, titanium, bromine, tin, tellurium, and silver. Organic chemical compounds (total organic carbon, or TOC) can also migrate through the vadose zone, as can the radiological compounds of uranium, thorium, and radium-226.

Runnels (1976) discusses the geochemical interactions of wastewater in the vadose zones of arid regions.

The bacteriological content of water leaving the vadose zone should be low due to pollutant attenuation in the topsoil and vadose zone.

Of the major inorganic chemical constituents, sodium and chloride are relatively mobile. Calcium, magnesium, bicarbonate, and sulfate may be precipitated out in the vadose zone. However, these and other constituents may be dissolved from minerals by water percolating through the vadose zone. Nitrate is relatively mobile and iron and manganese are generally immobile under aerobic conditions.

At least three major sources of data can be used to assess trace element mobility in the vadose zone. First, numerous leaching studies have been performed for specific elements applied to specific soils. Second, the general geochemical behavior for many trace elements in natural water systems is fairly well defined. Third, the occurrence of selected trace elements in groundwater is generally known.

Keeney and Wildung (1977) summarize soil interactions with trace metals. Fuller (1977) presents a detailed discussion of trace element mobility in soils. He states that numerous factors control pollutant mobility, but in general the following are most significant:

- Soil texture or particle size
- Pore space distribution in the soil
- Content and distribution of iron, aluminum, and manganese oxides and hydroxides in the soil
- pH of the soil and percolating waters
- Oxidation-reduction potential in the soil
- Organic matter content of soils and percolating waters
- Concentration of trace elements.

Selenium was found to be relatively mobile under aerobic conditions such as might be present in the vadose zone. Iron, zinc, lead, copper, and beryllium were moderately mobile. Arsenic, cadmium, chromium, and mercury were slowly mobile.

Hem (1970) discusses the occurrence of a number of trace elements in natural waters. Beryllium is generally not present in dissolved form in such waters because of its low solubility. Strontium contents are greatly limited by sulfate contents as high as those in the groundwater of the Gillette area. Barium can also be adsorbed by metal oxides or hydroxides and thus generally occurs in only small concentrations in groundwater. Titanium is not present in high concentrations in natural water because of the low solubility of its oxides and hydroxides. Vanadium appears to be soluble in groundwater under anaerobic conditions and may be present in significant concentrations if a source is present.

Numerous instances of chromium contamination of groundwater have been documented. The anionic species are apparently relatively stable in many groundwater systems. Molybdenum is predominantly present in the anionic form in groundwater. There appears to be no effective solubility control over molybdenum concentrations and thus large values may be found if a source is present. Cobalt content in groundwater is likely controlled by manganese or iron oxides and hydroxides and generally is low in groundwater. The general geochemical behavior of nickel is similar to that of cobalt.

The solubility of cupric oxide and hydroxy-carbonate minerals tends to limit the content of copper in groundwater to low values. Silver content is limited by the solubility of silver oxide and silver chloride. In dilute aerated water the equilibrium concentration of silver should be less than 0.01 ppm. Concentrations of zinc exceeding 1 ppm can be in groundwater. Cadmium contents in groundwater are generally very low; however, some cases of cadmium contamination have been documented for groundwater. Very few natural waters contain detectable concentrations of mercury.

Lead content is controlled by bicarbonate and sulfate contents. Lead sulfate is relatively insoluble, particularly in aerobic situations. Arsenic can be present in the anionic form over the pH range of most natural waters. Numerous occurrences of arsenic in groundwater under anaerobic conditions have been documented. The sorption of arsenate on ferric hydroxide or other active surfaces is likely an important factor limiting arsenic contents in natural waters. The stable form of selenium in aerobic groundwater is the anion form but little information is available on selenite solubility. Bromide has a geochemical behavior similar to chloride, and thus can occur in relatively high contents in groundwater.

Groundwater quality studies throughout the U.S. indicate that the trace elements chromium, vanadium, arsenic, cadmium, selenium, molybdenum, and bromine have been found in high concentrations in certain hydrogeologic situations. All of these elements readily form anions in the soil-groundwater system and may be mobile in the vadose zone. Studies of hazardous waste disposal summarized by the U.S. Environmental Protection Agency (1976c) indicate that the results of soil-leaching studies are consistent with these observations. These constituents should thus be given priority over other trace elements in a monitoring program.

Organic chemicals may move with percolating water through the vadose zone. However, the organic chemicals to be expected in water that contacts materials such as coaly wastes have not been well defined. Leenheer and Huffman (1976) have proposed a classification scheme for organic solute characterization. The scheme begins with dissolved organic carbon and is further divided on the basis of solute sorption and acid-base characteristics. Little is known about the mobility of the organic chemical fraction of wastes that comprise the spoils.

COAL CONVERSION

Anticipated Conversion Mechanisms

Of the three important types of coal conversion anticipated to be implemented in the project area – steam electric, gasification, and liquification – only steam electric currently is operating at a level where significant impacts are expected.

Steam Electric Power Plants

Water disposal at the Wyodak power plant consists of solid fly ash landfilled in the pits and fly ash slurry which is disposed of in a pond.

Pollutant mobility in the vadose zone for fly ash disposed of above the water table is somewhat similar, in the hydrologic sense, to that for spoils. The cases of primary concern would be point or line sources superimposed on the buried fly ash. At Wyodak this could be percolation of Donkey Creek streamflow after spoils and fly ash are emplaced. Also, holding or storage ponds could permit large amounts of percolation in local areas. Little is known about the hydrologic characteristics of a vadose zone comprised of landfilled fly ash.

For the fly ash slurry pond in the North Pit, the introduction of substantial amounts of water is planned, and this can be an important source of water for leaching materials in the slurry pond to the water table.

For fly ash, major potential inorganic chemical pollutants include calcium, magnesium, sodium, potassium, carbonates, chlorides, sulfates, boron, fluorides, iron, manganese, nitrogen oxides, and phosphorus oxides. Trace elements include vanadium, nickel, copper, zinc, arsenic, selenium, lead, antimony, titanium, rubidium, strontium, barium, cadmium, cobalt, chromium, molybdenum, cesium, bromine, silver, tungsten, iodine, mercury, lithium, zirconium, beryllium, and tellurium. Radiological pollutants are uranium, thorium, and radium.

The discussion on pollutant attenuation in the vadose zone for spoils is generally applicable to fly ash. However, in fly ash, the concentrations of some trace metals are particularly high and are of concern. Vanadium, molybdenum, and cadmium occur in high concentration and are possibly mobile. Arsenic, selenium, bromine, and iodine should receive priority for monitoring of waters contacting fly ash. The major constituents, total dissolved solids, fluorine, and boron should also receive priority.

MUNICIPAL

The three major municipal pollution sources are the Gillette landfill, sewage treatment plant, and water treatment plant.

Landfill

For convenience, the mobility of pollutants underlying the following areas are treated together: (1) metal disposal area and the tire disposal area; (2) oily waste disposal areas and the septic tank pumpage area; (3) the dead animal pit; and (4) the garbage disposal area.

Metal Disposal Area and Tire Disposal Area –

Potential pollutants in the metal disposal area may consist of trace contaminants from metals; organics in hazardous waste containers; freons, and possibly microorganisms. Pollutants in the tire disposal area may consist primarily of oily wastes, since tires are relatively stable.

The vadose zone underlying the metal disposal and tire disposal areas is undefined at this time. However, extrapolating from the profile exposed in the garbage trenches, it appears that the soil profile is relatively thin and underlain by bedrock sandstones or shales. In turn, overburden may merge at a shallow depth with a coal seam. Water movement in both the overburden and coal occurs primarily through fractures. Depth to water table is unknown. Because the landfill is located on a knoll, however, it would appear that water levels may be fairly deep, perhaps as much as 100 to 200 feet.

Mobility of trace contaminants through the relatively thin soil profile may be governed primarily by the factors listed by Korte et al. (1977) as soil texture, surface area, percentage of free oxides, and pH. The figures of Korte et al. (1977), reproduced as Figures 8-1 and 8-2, will be used to estimate the mobility of trace elements. Assuming also that the soils at the disposal site are similar to Mohave sandy loam, the mobilities of copper and lead will be low; and beryllium, zinc, cadmium, nickel, and mercury mobilities will be moderate. Similarly, the mobilities of selenium, vanadium, arsenic, and chromium may be high in the landfill soils.

Movement of trace contaminants in the shale or sandstone overburden may occur primarily through cracks and fissures. The interactions of contaminants with the solid matrix may not be as significant as those occurring during flow through the soil. It is known, for example, that salts are more readily leached through a well-structured soil by unsaturated rather than saturated flow (Biggar and Nielsen, 1967). Iron-oxide coatings have been observed in overburden samples from the mine sites. If such deposits occur in the landfill, overburden trace contaminants may become sorbed (Keeney and Wildung, 1977).

Because of insufficient data, it is not possible to quantitatively describe the movement and attenuation of trace contaminants in the coal seam. However, trace metals may accumulate at the interface between overburden and coal by some undefined process. Drever et al. (1977), for example, noted such an accumulation of trace metals in a coal-overburden interface on the

Black Thunder mine. The presence of partings above the coal with low pH values suggests that the mobilities of cationic metals may have been augmented in this region.

Movement of trace metals in the coal seam will occur through fractures. Again, data are not available to permit the prediction of metal attenuation.

Movement of organics may be moderated by the following mechanisms: sorption, lowering of the pH into the acid range, and microbial decomposition. Sorption may be a factor in the soil profile, but may be insignificant in the remainder of the vadose zone. The action of microorganisms may be of primary importance in attenuating organics from the source. Details are discussed below in the section on oily wastes.

Movement of pesticides from containers scattered throughout the area is difficult to predict without soils data. Davidson et al. (1976) point out that "...pesticide movement through the soil and into the groundwater may be increased significantly owing to adsorption-desorption characteristics of a pesticide at high concentrations." Davidson et al. (1976) used the Freundlich equation to characterize pesticide mobility in a silty clay loam soil.

Movement of microorganisms in the vadose zone underlying the metal disposal and tire areas may be restricted primarily by sorption and filtration with the shallow soil profile. Further movement into the underlying fractured bedrock may not be inhibited by those effects. The presence of pesticides at waste or container concentrations may reduce or stop the activity of otherwise viable soil microorganisms (Davidson et al., 1976).

Oily Waste Disposal Areas and Septic Tank Pumpage Area —

Oily wastes probably consist of spent petroleum substances such as lubricants, transmission fluid, as well as additives, and some hazardous wastes. Because of decomposition of organics, inorganics tend to concentrate. Trace contaminants may also accumulate.

The disposal pits for these areas appear to be constructed in bedrock. Consequently, the ameliorating effects of the soil profile on pollutant mobility may be minimal.

Because surface reactions of pollutants within bedrock cracks and fissures are probably minimal, the mobility of macro-constituents within the vadose zone may be restricted primarily by precipitation reactions. For example, calcium carbonate and calcium sulfate may precipitate. Precipitated gypsum is evident in the coal seam within the garbage trench. Similarly, precipitates of limonite [$Fe(OH)_2$] may occur. Precipitates may clog fractures to the point that infiltration will be inhibited—thus restricting mobility. Because of anaerobic conditions within the pits, nitrogen will tend to remain in the organic or ammonium forms. Leakage of wastes into the vadose zone, however, may expose these nitrogenous forms to sufficient oxygen to permit nitrification to take place. Nitrates will then flow farther into the vadose region.

Mobility of trace contaminants (e.g., lead in oily waste) may be affected

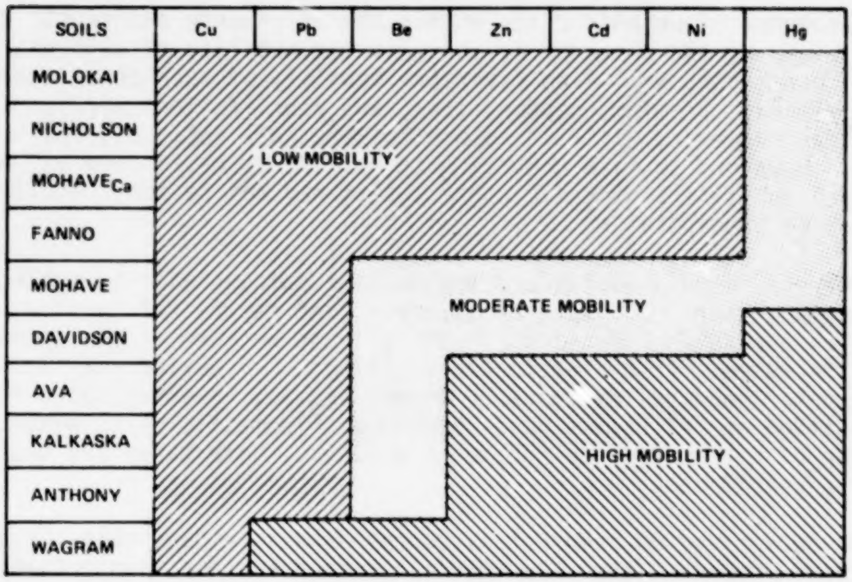
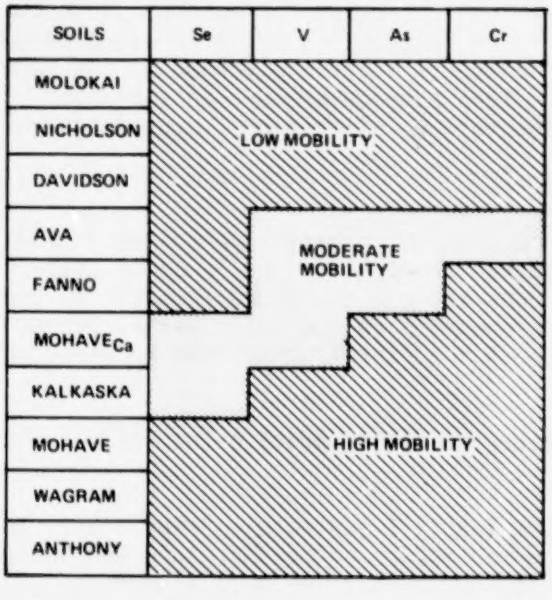

SOILS
Cu
Pb
Be
Zn
Cd
Ni
Hg
MOLOKAI
NICHOLSON
MOHAVE$_{Ca}$
FANNO
MOHAVE
DAVIDSON
AVA
KALKASKA
ANTHONY
WAGRAM
LOW MOBILITY
MODERATE MOBILITY
HIGH MOBILITY

Figure 8-1. Mobility of copper, lead, beryllium, zinc, cadmium, nickel, and mercury through 10 soils series (from Korte et al., 1977).


SOILS
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V
As
Cr
MOLOKAI
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DAVIDSON
AVA
FANNO
MOHAVE$_{Ca}$
KALKASKA
MOHAVE
WAGRAM
ANTHONY
LOW MOBILITY
MODERATE MOBILITY
HIGH MOBILITY

Figure 8-2. Mobility of selenium, vanadium, arsenic, and chromium through 10 soils series (from Korte et al., 1977).

by the presence of organic acids within the oily waste and septic disposal ponds. Lowering the pH tends to increase the mobility of cationic heavy metals. Reducing conditions will also favor the mobility of such constituents as arsenic, beryllium, chromium, copper, iron, and zinc (Fuller, 1977). The presence of sulfides, however, will act to precipitate FeS, ZnS, CdS, PbS, CuS, Hg_2S, and HgS. However, sulfate reduction to sulfide is restricted at lower pH values and mobilities of trace contaminants may not be too inhibited by the formation of precipitates.

Organics in oily wastes and septic tank pumpage will be subjected to microbial decomposition. The rate of decomposition may be fairly slow, however, because of anaerobic conditions in the pit and because of the chemical complexity of the waste. According to Grove (1975): "...buried oily waste will remain unchanged for hundreds of years." Streng (1976), however, notes microbial decomposition of refinery sludge, buried with domestic solid waste, by the evolution of carbon dioxide and methane gases. Both gases are evolved under anaerobic conditions.

The subsurface movement of microorganisms is a particular problem in the septic tank pumpage sites. Because filtration and sorption mechanisms afforded by the soil will be bypassed, microorganisms flow directly into cracks and fissures. If these cracks are fine enough, some filtration may be affected. However, attenuation will occur primarily by effects such as pH, temperature, and salt content on the viability of microorganisms.

Dead Animal Pit –

The dead animal pit also appears to be excavated into bedrock. However, dead animals are covered with crushed overburden. Principal contaminants within the dead animal pit are principally organics and pathogenic organisms. Mobility of these constituents will be governed by the same mechanisms for the oily wastes and septic tank pumpage areas. In addition, the crushed overburden may afford a certain degree of filtration of organics and bacteria.

Garbage Disposal Area –

Domestic and commercial solid wastes generated in the Gillette area are disposed of in the garbage trenches at the landfill site. The trenches may be as much as 33 feet deep and are excavated through the overburden into the coal seam. Leachate production in the solid wastes buried in the landfill is favored by surface runoff into the trenches and by groundwater seepage through the coal seams.

Pohland and Engelbrecht (1976) provide the following useful description of leachate:

> Sanitary landfill leachate is very likely to have a very high concentration of both organic and inorganic constituents, including heavy metals; accordingly, the concentration of total dissolved solids will be high. The pH of leachate is most often in the acidic range. However, the exact nature of leachate will depend upon such factors as

the composition of the solid wastes placed in the landfill and the degree of chemical and biological activity. These factors, along with residence time or the age of the material in the landfill, largely influence the chemical and physical characteristics of leachate. The presence of pathogenic or infectious agents will be a function of: (1) the density and nature of the pathogens placed in a landfill; (2) the ability of the pathogens to survive or to retain their infectivity in the landfill environment or the leachate; and (3) the ability of the pathogens to move through the landfill with the leachate into the surrounding environment. Because of its chemical, physical and/or biological properties, leachate can potentially impair the surrounding environment, i.e., nearby surface water or groundwater.

Because leachate will move from the base of the landfill trenches into a fractured rather than porous matrix, attenuating mechanisms, such as those associated with soils, may be minimal. In fact, internal modifications within the landfill may be more important in attenuating pollutants. Such modifications are described by Pohland and Engelbrecht (1976). Internal modification of leachate will occur via undefined physical-chemical reactions among liquid, solid, and gaseous phases. "Chemical changes occurring may involve oxidation-reduction reactions, coagulation, and acid-base reactions, while physical changes may result from filtration, ion exchange, sorption and precipitation." As a result of such reactions, solid wastes will become stabilized and the quality of leachate will change. The concentration of organic matter and physical and chemical constituents will gradually decrease.

Leachate initially contains excessive concentrations of the major chemical constituents, calcium, magnesium, sodium, potassium, sulfate, and bicarbonate. The mobilities of certain of these constituents are controlled to some extent by microbial activity within the landfill. In particular, biological stabilization of organics results in carbon dioxide (CO_2) production and leads to the formation of carbonic acid. The pH of leachate is reduced into the acid range. The solubility of calcium carbonate is increased by carbon dioxide production and a lowered pH so that the mobilities of calcium and bicarbonate ions will be augmented. Eventually, however, the pH may be increased in the vadose zone flow system such that calcium carbonate will precipitate. High concentrations of sulfate observed in runoff water within the garbage trench suggest that precipitation of gypsum may occur within the coal seam. Both calcium and sulfate would then be removed from the flow system.

The solubility of magnesium carbonate is also influenced by the presence of carbon dioxide and free movement within the vadose zone would be expected. Similarly, sodium and potassium salts are soluble unless concentrations are increased to several thousand parts per million. Mobilities of these salts will probably be slight.

The anaerobic environment within the landfill will prohibit nitrification of organic and ammonium nitrogen. However, both nitrogen and ammonium nitrogen may move to some extent into the coal seam. Sorption of ammonium nitrogen will be minimal because clays are not present. If sufficient oxygen becomes available in the flow system, nitrification of ammonium nitrogen may eventually occur.

The mobility of trace elements in the vadose zone will be of particular concern in the initial leachate. At that time, carbon dioxide evolution by microorganisms will be at a maximum, resulting in the production of carbonic acid. Organic acids will also be abundant. As pointed out above, the mobilities of cationic metals are enhanced in lower pH ranges. Similarly, if reducing conditions are obtained, the mobility of the following trace contaminants will be increased: arsenic, beryllium, chromium, copper, cyanide, iron, and zinc (Fuller, 1977). Organic acids may also favor the production of organic complexes with trace contaminants, increasing their mobilities. In contrast to these mechanisms favoring the mobility of trace metals, precipitation of certain metals will occur in the presence of sulfides, including FeS, ZnS, CdS, PbS, CuS, Hg_2S and HgS. In order for such sulfides to form, however, it will be necessary for the pH to increase into a range favorable to sulfur-reducing microorganisms.

The mobility of organics in landfill leachate will probably not be inhibited by sorption. The relatively high TDS of leachate, however, may favor the flux of organics (Metcalf and Eddy, 1975). Possibly the principal mechanism for retarding the movement of organics will be microbial stabilization. A secondary effect may be that some organics may precipitate in low pH leachate. Leenheer and Huffman (1976) note the formation of an organic precipitate upon acidification of a groundwater sample for an oil shale area in Wyoming.

Regarding microorganisms, Pohland and Engelbrecht (1976) indicate: "...a significant reduction in the population of microorganisms can be expected with time... The decrease in density of biological indicators of fecal pollution would indicate that leachate would not likely show many, if any, pathogenic microorganisms. Examination of leachate for enteric viruses has confirmed this; further, it has been demonstrated that leachate, because of certain of its chemical constituents, has the capacity to inactivate pathogenic bacteria and enteric viruses... As a consequence, the chemical and physical characteristics of leachate are probably potentially more significant in terms of impact on the surrounding environment than its biological properties."

From the above it appears that the leachate initially flowing into the vadose zone will mainly contribute microorganisms. Again, because of the limited capability of the coal seam to filter and sorb organisms, mobility may be relatively unrestricted. Some sedimentation of bacteria may occur and environmental conditions may be conducive to die-off. Viruses, however, would probably flow for a considerable distance.

Sewage Treatment Plant

Section 7 discusses the infiltration potential of several potential sources of groundwater pollution. The following discussions generalize on the mechanisms which govern the mobility of the pollutants entering the vadose zone.

Treatment Plant Facilities –

Lack of field data precludes an exact definition of the nature and extent of the vadose zone at the plant site. Also, if the supposition of City of Gillette officials is correct, the vadose zone may be completely bypassed during leakage of pollutants from the tanks. As a first estimate, therefore, attenuation of these pollutants in the vadose zone is minimal.

Oxidation Pond –

The factors and constituents discussed below will greatly influence the mobility of pollutants carried by seepage from the oxidation pond.

Macroconstituents – The principal macroconstituents in lagoon seepage will be similar to those discussed previously for leakage from the wastewater tanks: calcium, sodium, phosphate, sulfate, bicarbonate, and nitrogen. Reactions will be similar except as moderated by aerobic conditions within the unsaturated flow regime. Calcium will tend to form precipitates with bicarbonate and sulfate and compete with sodium for exchange sites on clay and organic surfaces. Phosphate mobility is strongly restricted because of interaction with carbonates, hydrous oxides, and silicate minerals (Keeney and Wildung, 1977).

In the anaerobic environment of the "oxidation" pond, organic nitrogen may be mineralized to ammonia but nitrification will be inhibited. Migration of ammonia into the vadose zone may be restricted because of sorption on the organics within the benthos. Further below the benthos-soil interface, ammonia may become fixed on clay mineral surfaces or become involved in exchange reactions. If oxygen levels are sufficiently high in the unsaturated media and if a source of organic food supply is available, nitrification may occur. However, because of the shallow depth to the water table at the pond site, it is difficult to predict the extent of nitrification.

Trace pollutants – The possibility of polluting the groundwater beneath the lagoon at Gillette with heavy metals was pointed out previously in the discussion above on trace pollutants. For example, Lund et al. (1976) observed heavy metals in soil solution extracts 10 feet below the base of effluent ponds constructed in coarse textured soils. Metal concentrations in the infiltration from the pond will be lower, however, than the corresponding levels in infiltration from the sludge pond, because sludges accumulate heavy metals. Levels of zinc may be particularly high (Ms. Paddock, Supervisor, water and wastewater plants, City of Gillette, personal communication).

Fuller (1977) listed the following 10 general factors as important in migration of heavy metals in soils: hydrogen ion activity (pH), oxidation reduction, particle size distribution of soils (surface area), pore size distribution, lime, organic matter, concentration of ions or salts, certain hydrous oxides, climate (weathering), and aerobic and anaerobic conditions. In controlled laboratory experiments, Korte et al. (1977) found that the following soil properties were dominant in influencing trace pollutant mobility: soil texture and surface area, percentage of free oxides, and pH.

As a first estimate of the mobility of heavy metals in the vadose zone underlying the pond, the figures developed by Korte et al (1977) on the relative mobility of cations in the seven most prominant soil orders in the U.S. are utilized. These figures are reproduced as Figures 8-1 and 8-2. Characteristics of the soils used in the study by Korte et al. (1977) are reproduced in Table 8-1. Comparing soils in Table 8-1 with soils in the Gillette area, it appears that of the soils evaluated by Korte (Figures 8-1 and 8-2), the Mohave sandy loam is the most comparable to the Gillette area soils. Figure 8-1 shows that copper and lead have low mobilities; beryllium, zinc, cadmium, nickel, and mercury have moderate mobilities. Similarly, Figure 8-2 shows that the following metals have high mobility: selenium, vanadium, arsenic, and chromium.

Regarding the mobility of zinc, Fuller (1977) indicates that Zn^{++} forms slowly soluble precipitates with carbonate, sulfides, silicate, and phosphate ions. (The presence of sulfide in water seeping from the pond is highly likely.)

The mobility of trace metals in soils will be moderated by the presence of organics. Digestion in anaerobic ponds leads to the formation of organic acids, lowering the pH. The mobility of cationic heavy metals increases as the pH decreases. Consequently, metals may penetrate the vadose zone beneath the pond to the depth that organic acids are neutralized.

Finally, the formation of metal-organic chelates may increase the mobility of some trace contaminants.

Organic pollutants – The mobility of organics is affected by the factors discussed under Treatment Plant Facilities: sorption, pH, TDS, and microorganisms. Of possible relevance to the migration of organics beneath the pond are results of studies by Schaub et al. (1975) on rapid infiltration of waste water. In particular, soil samples from active cells were observed to contain high levels of TOC and heavy metals in a "black asphaltic" layer at a depth of about 18 inches.

Microorganisms – Mobility of microorganisms will be influenced by filtration, sedimentation, and sorption mechanisms. The flux of viruses, in particular, will be affected by salt concentration,adsorption, pH, organic matter, and infiltration rates. Quantitative data are needed to determine the relative effect of these mechanisms on virus movement in the vadose zone underlying the Gillette pond site.

Sludge Disposal Pond –

Factors affecting the mobility of contaminants in the vadose zone are essentially identical to those discussed above for the "oxidation" pond. However, the levels of heavy metals will be greater because of the tendency of sludges to accumulate metals. All metals are present in excessive concentration, but the levels of lead, copper, and zinc are particularly high.

TABLE 8-1. CHARACTERISTICS OF THE SOILS (from Korte et al., 1977)

Soil	Order	pH	CEC (me/100 g)	EC (μmhos/cm)	Surface area (m^2/g)	Free iron oxides (percent)	Total Mn (ppm)	Sand (percent)	Silt (percent)	Clay (percent)	Texture class	Predominant clay minerals[b]
Wagram (N. Carolina)	Utisol	4.2	2	225	8.0	0.6	50	88	8	4	loamy sand	Kaolinite, chlorite
Ava (Illinois)	Alfisol	4.5	19	157	61.5	4.0	360	10	60	31	silty clay loam	Vermiculite, kaolinite
Kalkaska (Michigan)	Spodosol	4.7	10	237	8.9	1.8	80	91	4	5	sand	Chlorite, kaolinite
Davidson (N. Carolina)	Ultisol	6.2	9	169	51.3	17	4,100	19	20	61	clay	Kaolinite
Molokai (Hawaii)	Oxisol	6.2	14	1,262	67.3	23	7,400	23	25	52	clay	Kaolinite, gibbsite
Chalmers (Indiana)	Mollisol	6.6	26	288	125.6	3.1	330	7	58	35	silty clay loam	Montmorillonite, vermiculite
Nicholson (Kentucky)	Alfisol	6.7	37	176	120.5	5.6	950	3	47	49	silty clay	Vermiculite
Fanno (Arizona)	Alfisol	7.0	33	392	122.1	3.7	280	35	19	46	clay	Montmorillonite, mica
Mohave (Arizona)	Aridisol	7.3	10	615	38.3	1.7	825	52	37	11	sandy loam	Mica, kaolinite
Mohave (Arizona)	Aridisol	7.8	12	510	127.5	2.5	770	32	28	40	clay loam	Mica, montmorillonite
Anthony (Arizona)	Entisol	7.8	6	328	19.8	1.8	275	71	14	15	sandy loam	Montmorillonite, mica

[a] Listed in order of importance.

Studies by Lund et al. (1976) demonstrated that heavy metals migrate to depths as great as 10 feet below anaerobically digested sludge holding ponds. The metals examined were zinc, cadmium, copper, chromium, and nickel. The soils were coarse textured. The authors found that redistribution of metals was closely related to change in COD of soil samples with depth. Metal movement was thus attributed to the formation of organic chelates. Other possible factors promoting metal migration include pH and oxidation reduction potential. For example, during the first stage of anaerobic digestion of sludge, organic acid formation lowers the pH to a value of about 5.1 (Health Education Service, nd). The lower pH promotes the flux of cationic heavy metals (Fuller, 1977). Also, according to Fuller, reducing conditions in soil promote the movement of arsenic, beryllium, chromium, copper, cyanide, iron, and zinc, but have little effect on the movement of cadmium, lead, and mercury.

Anaerobic conditions obviously occur in both the sludge lagoon and "oxidation" pond at the Gillette wastewater treatment plant. Because of the shallow water table at this site, heavy metals may be introduced almost directly into the aquifer.

Donkey Creek –

Mobility of pollutants in the vadose zone will be affected by mechanisms discussed in detail for treatment plant facilities, the "oxidation" pond, and the sludge disposal pond. However, the areal extent of the vadose zone contacted by the pollutants is far greater than for the essentially point sources. As a result, attenuation mechanisms associated with exchange, sorption, etc., are enhanced.

Periodic flows of snowmelt or rainfall runoff may dilute or flush out the vadose zone to some extent. The exchange capacity, or sorption sites, may be rejuvenated by such dilution. However, snowmelt may increase the mobility of viruses. Lance et al. (1976) observed the desorption and migration of viruses in soil columns following application of deionized water. Columns were previously flooded with secondary sewage effluent.

Water Treatment Plant

The hand dug disposal well essentially bypasses the vadose zone. Most wastewater is disposed of into Stone Pile Creek. Wastewater infiltration into Stone Pile Creek will enter the vadose zone as a line source. The vadose zone is probably about 80 feet thick in the vicinity of the water treatment plant. No information is available on the lithology of the vadose zone. However, some floodplain alluvium may be present in the vicinity of Stone Pile Creek. The alluvium probably merges with bedrock at a shallow depth. Water movement in the bedrock may be restricted primarily to cracks or fissures.

Attenuation of major chemical constituents in the alluvium may be governed to some extent by processes observed in soils, e.g., sorption and exchange reactions, and precipitation-solution reactions. The high concentrations of salts or brine from the electrodialysis plant may favor the formation of calcium and magnesium carbonates, gypsum, and even some sodium precipitates. The mobility of chloride will not be affected. The exchange complex of the limited amount of clays in the alluvium probably would be quickly swamped. Precipitation may similarly limit the movement of major constituents into the fractured bedrock underlying the alluvium.

The mobility of constituents in the lime softener wastewater will be greater than for the electrodialysis brine because the relatively low salt concentrations will not favor precipitation. Some sorption or exchange reactions may occur; however, movement into the underlying bedrock will probably be inhibited.

Mobility of tract constituents will be governed by such factors as pH, reducing conditions, presence of hydrous oxides, and sorption. If the discharge of electrodialysis brine or softening plant wastewater is fairly continuous, anaerobic conditions will develop in a shallow subsurface zone of the channel. A characteristic of such a regime is that sulfate will be reduced to sulfide, leading to the formation of insoluble precipitates such as iron sulfate, cadmium sulfate, zinc sulfate, lead sulfate, copper sulfate, and mercury sulfate. In contrast, however, reducing conditions increase the mobility of arsenic, beryllium, chromium, copper, cyanide, iron, and zinc. Cyanide will denitrify and evolve as a gas (Fuller, 1977). Organic acids, formed for example from decaying channel vegetation, may lower the pH sufficiently that the mobilities of cationic trace metals will be increased. Chelation of metals with organics will also increase mobility.

SECTION 9

POLLUTANT MOBILITY IN THE SATURATED ZONE

Pollutants which are conservative in nature or manage to pass through the various attenuation mechanisms present in the vadose zone are of concern in this section. These pollutants are still subject to the attenuating mechanisms of the saturated zone, i.e., buffering, chemical precipitation, filtering, and dilution.

If upon entering the zone of saturation a pollutant becomes immobile due to one of these mechanisms, it becomes a philosophical question as to whether groundwater quality degradation has taken place or whether the assimilative capacity of the subsurface environment is being utilized. The solution to this question lies in the proximity of existing or potential usage to the deposited pollutant.

Pollutants which prove to be mobile in the saturated zone may eventually result in damage to existing or future groundwater usage. The concentration and toxicity of a particular pollutant and the proximity of a discharge point for usage to the point of entry of the pollutant to the zone of saturation will greatly influence the threat associated with a particular source.

COAL STRIP MINING

The two sources in this class which are expected to result in pollutants reaching the saturated zone are pit discharges disposed of in certain ways, and spoils.

Pit Discharge (Active Mining Area Source)

For pit discharge, the primary processes of concern for monitoring in the saturated zone are percolation from polluted streamflow and seepage from holding or storage ponds. In the case of disposal to surface water, the primary method of pollutant transport is by surface water flow. Although NPDES (National Pollution Discharge Elimination System) permits are required for such discharges, they are designed for surface water considerations rather than their effect on groundwater. In addition, the present discharge requirements are fragmentary in nature and are not comprehensive. Although pollutants could be carried some distance downstream from the point of discharge, substantial dilution could also occur at the same time. Rates of groundwater movement in the alluvial aquifers have been discussed under the following material on spoils. Monitor wells should generally be placed as close to the stream channel as possible. For percolation from holding ponds (a point source), considerations discussed under the following discussion on spoils will be applicable. That is, flow rates in the consolidated formations are generally slow and monitor wells must be located in immediate proximity to the source.

Spoils (Reclaimed Area Source)

Two major types of waste disposal involving spoils can be considered:

- Direct emplacement of spoils below the equilibrium water level (after pit dewatering is ceased)
- Movement of liquids through the spoils to the water table.

This latter type has been previously addressed in Section 7 (Infiltration Potential) and Section 8 (Mobility of Pollutants in the Vadose Zone). Again, mobility can be discussed in terms of (1) water movement, and (2) pollutant transport and attenuation mechanisms.

For spoils directly emplaced into areas that will be below the groundwater level after active mining stops, no pollutant attenuation will have previously occurred. As groundwater contacts the spoils, numerous pollutants will directly enter the groundwater. In situations where spoils are in contact with fractured rock, such as at the bottom of former pits, pollutants may be directly introduced to groundwater in fractures. Less pollutant attenuation due to physical and biologic factors may occur under this circumstance than any other. An important factor is that the lower part of the spoils will often be the depository for materials with the highest pollution potential. Examples are toxic soils, clay layers near the coal or interlayers, and waste coal.

Some constituents in liquids moving through all or part of the vadose zone in the spoils will have the opportunity for substantial attenuation. However, numerous pollutants will likely be picked up by the percolating water. The major important cases would be for streamflow percolation and for seepage from holding or storage ponds on the spoils.

Polluted groundwater in the spoils can be viewed as a diffuse source in the hydrologic sense in that, after mining is completed, large areas could be affected. The rate of movement of the polluted groundwater depends on aquifer transmissivity, porosity, and the hydraulic gradient. Aquifers potentially impacted include shallow alluvium, nearby downgradient coal beds, nearby downgradient overburden, and formations underlying the spoils. Surface water can also be impacted because in some areas the groundwater discharges to surface water.

Hydraulic characteristics of the spoils are poorly known and no aquifer tests have been reported for mines near Gillette. However, Rahn (1976) reported a transmissivity of 11,000 gpd per foot and a storage coefficient of 0.12 for a 27-hour pump test on a 33-foot thickness of saturated spoils at the Hidden Creek mine near Sheridan, Wyoming. Additional pump tests are necessary to adequately determine aquifer parameters for spoils in the Gillette area. Transmissivity of the Fort Union and Wasatch Formations, including the coal beds, commonly range from several hundred to several thousand gpd per foot. Based on present data, it appears that both the transmissivity and storage coefficient of spoils will generally be several times larger than those of the undisturbed consolidated formations. Aquifer characteristics for the alluvial aquifers are generally unknown.

The hydraulic gradient to be expected in spoils is unknown. However, King (1974) noted that hydraulic gradients in the more permeable aquifers of the Gillette area range from 10 to 25 feet per mile. Hydraulic gradients in the least permeable aquifers may exceed 100 feet per mile. The average hydraulic gradient for consolidated rock aquifers is probably about 40 to 50 feet per mile. The University of Wyoming (1976) reported on the extensive groundwater monitoring at the ARCO Black Thunder mine. The hydraulic gradient for the coal aquifer ranged from 15 to 40 feet per mile.

Porosities for different aquifer materials are not well known. However, an independent analysis of groundwater flow rate can be obtained from the results of carbon-14 age dating of groundwater at the Black Thunder mine. Ages in the range of 11,000 to 34,000 years for groundwater within several miles of the recharge point indicate very slow travel times, in the range of only several feet per year. Assuming a porosity of 0.10 for fractured consolidated rock, a groundwater flow rate of about 35 feet per year is calculated, based on average values for transmissivity and hydraulic gradient. Flow rates of groundwater in the spoils are generally unknown.

The rate of groundwater flow in the consolidated rock aquifers implies that polluted groundwater entering these aquifers would generally move very slowly. Thus monitor wells would have to be located very close to a potential source of pollution. It might require a thousand years for such water to flow only one-quarter of a mile. The key conclusion is that little effect on groundwater quality would be noticeable over the short term except in the immediate proximity of the source. Flow rates in the alluvial aquifers (underflow) could be much greater; however, these are generally unknown due to lack of data on aquifer characteristics and hydraulic gradient.

The monitoring of point and line sources would necessitate having wells as close to the surface as possible. For monitoring a diffuse source, such as the spoils, the wells can be constructed directly in the spoils. Vadose zone monitoring and land surface monitoring can provide information on travel times to the saturated zone and an indication of when polluted water might be expected to reach the water table.

The chemical aspects of pollutant transport and attenuation are not considered further because of the relatively slow groundwater flow rates, which exert the controlling factor on pollutant mobility in the saturated zone.

COAL CONVERSION

The one coal conversion activity of particular importance in the project area is steam electric power generation.

Steam Electric Power Generating Plants

At the Wyodak power plant, there are two methods of disposal to consider: solid fly ash landfilled in the pits, and the fly ash slurry pond. For the solid fly ash disposal, materials may be placed below the equilibrium water level. Thus, such materials would be in the saturated zone after mining ceases. Virtually no pollutant attenuation will have previously occurred. Previous discussions in Section 7 (Infiltration Potential) and Section 8 (Mobility of Pollutants in the Vadose Zone) apply to solid fly ash disposed above the equilibrium water level and to the fly ash slurry pond.

As groundwater enters the buried fly ash, a number of pollutants will directly enter the groundwater. In situations where solid fly ash is in contact with fractured rock, such as at the bottom of the pit, pollutants may be directly introduced to groundwater in fractures. Less pollutant attenuation due to physical and biologic factors may occur under this circumstance than any other. The solid fly ash disposal can be viewed as a diffuse source, as it will occur over a relatively large area. The rate of movement of groundwater in saturated fly ash is generally unknown.

A number of pollutants could be picked up as water moves vertically through the fly ash beneath the slurry pond, which can be viewed as a point source. For pollutants reaching the water table, similar considerations apply as those discussed for mining spoils pollutants. That is, groundwater movement in the consolidated rock aquifers is generally slow and monitor wells would have to be placed in immediate proximity to the pond.

MUNICIPAL SOURCES

All three sources discussed previously in Sections 7 and 8 also have potential for the production of pollutants which are likely to be mobile in the zone of saturation and thus may result in groundwater quality degradation.

Landfill

Relatively little information is available on the groundwater system beneath the landfill. According to a regional potentiometric surface map presented by Keefer and Hadley (1976), groundwater movement probably occurs in a northerly direction beneath the site. Consequently, pollutants moving into the groundwater flow system will move as a plume towards the City of Gillette well field. Because of slow velocities, however, the effect may not be noticeable for a considerable time.

Dilution may occur in the flow system, but, again, data are insufficient at this time to facilitate predictions, for example, by flow net analyses.

An extensive scoria deposit appears to underlie the northeastern region of the landfill site. Field observations suggest that this scoria deposit is highly permeable. For example, when the water tank above the landfill was drained onto the land surface recently, it was noted that the water infiltrated rapidly. Within a day, water was observed to bubble out at the base of the pit (courtesy Ms. Paddock). This observation suggests that snowmelt or runoff water may flow into the scoria and possibly into the underlying shallow aquifer system. Dilution of a leachate plume would subsequently result.

Sewage Treatment Plant

Again, because of the lack of data, mechanisms for attenuating pollutants in the saturated zone can be speculated upon only qualitatively at this time. As pointed out by Todd et al. (1976), similar mechanisms may be operative in both the vadose zone and saturated zone. In addition, a pollutant plume in the saturated region will be moderated by dilution with native groundwater.

Treatment Plant Facilities –

For convenience, potential treatment plant pollutants will be categorized as: macroinorganic, trace elements, organics, and microorganisms. It will also be assumed that the shallow aquifer system is within floodplain alluvium, so that flow occurs in a porous matrix, rather than through fractures.

Macroconstituents – Based on estimated wastewater quality for the City of Gillette (see Section 3, Table 3-18), it appears that the principal macroconstituents include calcium, sodium, sulfate, bicarbonate, phosphate, and nitrogen. Chemical controls on the mobility of calcium are reviewed by Hem (1970), including the tendency of calcium to precipitate with bicarbonate and sulfate.

For the flow system beneath the treatment plant, it may be possible to use a method developed by Hem (1970), Back and Hanshaw (1965), and Bower et al. (1965) to determine the tendency of $CaCO_3$ to precipitate. In addition to precipitation, calcium mobility may be limited by exchange reactions on clays. For this case, calcium will be in competition with sodium for exchange sites. The relative degree of sodium adsorption on clays is described by the sodium adsorption ratio, SAR:

$$SAR = Na^{+} / [(Ca^{++} + Mg^{++})/2]^{1/2}$$

Sulfate and bicarbonate mobilities are linked to reactions with calcium and magnesium. In addition, sulfate may be sorbed to a minor extent on the aquifer matrix and be retained by hydrous oxides of iron (Keeney and Wildung, 1977). The latter reactions, however, require low pH values. The presence of organic acids in tank seepage may have a local effect in reducing pH and consequently on sulfate mobility.

Phosphate retention and mobilities are discussed by Keeney and Wildung (1977). In acid soil, phosphorus is sorbed on the surface of Fe- and Al-containing minerals to form surface compounds. As pointed out above, organic acids present in tank leakage may have a local effect on lowering pH values and consequently promote the above reaction. However, eventually, organic acids will be neutralized in the predominantly alkaline groundwater system. For alkaline conditions, sorption of P on $CaCO_3$ or formation of Ca phosphate minerals may occur (Keeney and Wildung, 1977). Phosphate retention on clays and hydrous oxides may also be important in the saturated flow system.

Nitrogen mobility in the saturated system will involve only the organic-N and NH_4-N forms. That is, nitrification will be inhibited in the anaerobic environment. Organic-N may be removed by filtration or become involved in metal complexation reactions. Mobility of the ammonia form will be restricted primarily by exchange reactions on clay surfaces.

Trace pollutants – The flux of trace pollutants (i.e., heavy metals and trace metals) from the wastewater tanks will probably be markedly reduced because of the tendency of sludge to concentrate such metals. The metals entering the groundwater system will be affected by reactions in anaerobic systems. At the outset, it should be noted that the mobility of trace metals is greater in anaerobic than aerobic systems (Fuller, 1977). Thus, "Reducing conditions in soil promote mobility of most of the trace contaminants. Cadmium, lead, and mercury mobility may be little affected by the lack of oxygen as compared with As, Be, Cr, Cu, Cn, Fe, and Zn, which will migrate at a greater rate" (Fuller, 1977). If sulfides are present, however, anaerobic conditions may lead to the formation of relatively insoluble compounds such as FeS, ZnS, CdS, PbS, CuS, Hg_2S, and HgS. The presence of organic acids also affects the mobility of trace contaminants because cationic metals are mobile in the lower pH ranges. However, the flux of arsenic, selenium, and cyanide will not be appreciably affected. Organic acids may also favor the production of organic complexes with trace contaminants increasing their mobility.

The mobility of trace contaminants will be moderated also by exchange with clays and organic matter and adsorption reactions with hydrous oxides of Fe and Al.

Organics – High COD, TOC, and BOD values are undoubtedly present in tank seepage. Specifying the mobility of organics is difficult because quantitative studies have only recently been reported. One problem is that analytical procedures to identify organics are still being developed. Research is needed to improve capabilities to analyze samples comprehensively so that significance of trace organics in the environment can be determined (Donaldson, 1977). Recently, Leenheer and Huffman (1976) described the development of the dissolved organic carbon (DOC) technique for fractionating organics into hydrophobic and hydrophilic components using macroreticular resins. The technique was applied to several natural waters. This technique has advantages over other methods, such as activated carbon, for concentrating organics. For example, Robertson et al. (1974) reported that only 10 percent of organics present in groundwater beneath a landfill in Oklahoma were identified using carbon adsorption followed by carbon chloroform and carbon alcohol extraction.

Because of the limited information on attenuation of organics in a porous medium, only qualitative estimates of mobility can be presented at this time.

Sorption may be an important factor in attenuation. It is known, for example, that PCB's tend to be strongly adsorbed by soil and are also insoluble in water (Robertson et al., 1974). Leenheer and Huffman (1976) indicate that both hydrophobic and hydrophilic organics may be sorbed by sediment.

Leenheer and Huffman (1976) noted the formation of an organic precipitate upon acidification of a groundwater sample from an oil shale area near Rock

Springs, Wyoming. Raising the pH dissolved the precipitate. Possibly, in a localized situation, organic acids may lower the pH sufficiently that precipitation may be a factor. However, neutralization of acids would preclude precipitation of organics.

The relatively high TDS of wastewater may affect the mobility of organics. For example, in leaching studies on spent shale using a high TDS "foul water," Metcalf and Eddy (1975) observed about 55 percent reduction in organics expressed as TOC.

Finally, microorganisms may effect a removal of organics, for example, by the formation of methane, carbon dioxide, and other gases.

Microorganisms - Microorganisms entering groundwater from the tanks include fecal coliform, fecal strep, virus, amoeboid cysts, intestinal worm eggs, and parasitic fungi. The cysts, eggs, and fungi will be removed by filtration. Bacteria may be attenuated near the interface with the aquifer by filtration, sedimentation, and adsorption. Migration of virus may be moderated by adsorption rates (Gilbert et al., 1976). Studies by Schaub et al. (1975) on virus mobility in coarse soils of high-rate infiltration cells, indicated that viruses are capable of bypassing filtration and sorption mechanisms and penetrating groundwater. In fact, viruses were observed to migrate horizontally more than 600 feet from the source. Migration of viruses may occur in a similar fashion away from the tanks.

Dilution effects - The effects discussed above for attenuating the inorganic, organic, and microbiological sources will be supplemented by dilution in the water-bearing formation. The magnitude of dilution will require field data (currently not available) on volume of wastewater entering the water table, waste loading, areal hydraulic head distribution, transmissivity of the aquifer, vertical and horizontal hydraulic conductivity values, quantity and quality of recharge from other surfaces, and pumpage in the area (Todd et al., 1976).

Oxidation Pond -

The mechanisms of transport for pollutants from this source are similar to those discussed above for treatment plant facilities.

Sludge Disposal Pond -

The mechanisms of transport for pollutants from this source are also similar to those discussed above for treatment plant facilities.

Donkey Creek -

Mechanisms for attenuating pollutants in the shallow saturated region will be similar to those discussed above for treatment plant facilities. However, dilution effects may be magnified because of the larger surface area of the aquifer contacted by percolating wastewater. Also, periodic flows of snowmelt and thunderstorm discharge will enhance dilution.

Water Treatment Plant

Definitive information is not available on the hydraulic properties of the aquifer which receives recharge from the brine disposal well or from Stone Pile Creek. The potentiometric water surface is also unknown. Consequently, it is not possible to develop flow nets to estimate dilution of pollutants at this time. Mechanisms operating in the vadose zone may also contribute to attenuation of pollutants but, again, data are not available.

The regional potentiometric map of the aquifer system in the Gillette area by Keefer and Hadley (1976) shows that groundwater moves in a northerly direction. As a consequence, recharged electrodialysis brine or softening plant wastewater will flow toward the City of Gillette well field, which is a relatively short distance away.

SECTION 10

PRIORITY RANKING OF POTENTIAL GROUNDWATER POLLUTION SOURCES

Three major classifications of potential pollution sources have been inventoried, Agricultural, Industrial, and Municipal. The principal thrust of this inventory has been to review the existing information and data to determine what is known about the potential impact of the sources within these major classes on groundwater quality, and then make a preliminary (Level One) ranking based on this information.

AGRICULTURAL ACTIVITIES

Agricultural activities in the project area were inventoried for potential groundwater pollution sources. These sources were found to be insignificant due to their diffuse nature. Irrigated farmland is practically nonexistent and dryland farming is the general method. Most farming in the area is economically marginal. Cattle ranching is the primary agricultural activity. On the mine leases funds may become available which could result in reclamation activities which approach intensive agricultural activities. This could result in the presence of potential agricultural-related groundwater pollution sources such as leaching of inorganic nitrogen from mine spoils by irrigation waters used to establish vegetative cover, and from feedlots.

Based on the above observation, agricultural activities currently will require only limited surveillance, e.g., through aerial photography.

INDUSTRIAL

The Industrial classification includes Construction, Oil and Gas Extraction, Coal Strip Mining, and Coal Conversion activities. Of these four, coal strip mining and coal conversion are apparently the most significant in terms of potential groundwater quality degradation.

Construction

During the course of the potential pollution source inventory, it was observed that almost all of the wastes associated with the construction industry are either disposed of in the Gillette landfill, and as a result come under the Municipal wastes category, or are disposed of with mine solid wastes on the leases. The same can be said for sanitary wastes from the construction industry where the City or mine disposal facilities are utilized. The construction industry will continue to be given only limited surveillance to ensure that no changes in practice occur.

Oil and Gas Extraction

The oil and gas extraction industry clearly has considerable potential as a problem area. Field observations and conversations with farmers and ranchers indicate that good practices for handling oil field wastes are not in force. Infiltration pits and ponds are still commonly used for disposal of oil field wastes and brines. The Gillette landfill is also used for disposal of oily wastes and brines where these fluids are allowed to freely percolate into the subsurface. A reportedly common practice for disposal of oil field wastes is to truck the material to an isolated stretch of road and open the discharge valve while moving.

The Wyoming Oil and Gas Commission has been contacted to identify their involvement in monitoring. It was found, however, that this agency is involved in leasing matters and compilation of exploration and production statistics and that little monitoring is done.

The oil and gas extraction industry is probably a major potential groundwater pollution source, however, it will not be investigated in a regional sense in this study. On mine leases where oil and gas wells exist or have existed, potential groundwater impacts will be evaluated. Based on information collected so far, these wells are of minor concern because they are so few in number, and are under close scrutiny because of their proximity to the mining operations.

Coal Strip Mining

Coal strip mining and its related sources have considerable potential to produce groundwater quality degradation. Certain sources have considerably more potential for harm than others. As should be evident from the discussion in the previous sections, only limited monitoring has been carried out on the sources identified in Section 2. Where monitoring of sources has been conducted it has not been source oriented but directed toward assessing background quality levels, with the hope that eventually any changes in quality due to pollutants will show up in the monitoring program.

The above approach is the traditional approach utilized, but it is contrary to the objectives of Public Laws 92-500 and 93-523, which are aimed at preventing, reducing, and eliminating groundwater quality degradation. Once pollutants show up in a background quality monitoring system, in many cases, it is too late to institute controls. Source monitoring is the key to determining which controls to implement and whether they are working.

Seven coal strip mining operations in various stages of development were inventoried in Section 2 for potential groundwater pollution sources. Differences in the kinds of sources present exist as well as in the methods of disposal used. Sufficient information does not exist to develop a priority ranking for each individual mine site nor for all the sites collectively. No monitoring is underway on many of the sources. As a result, the preliminary ranking which follows will relate only to two major coal strip mining related sources: pit discharges, and spoils.

For active mining, the pit discharge represents a potential source of groundwater pollution. Much of the pit discharge is derived from native groundwater, and this may not appear to be an important source. However, a number of potential pollutants can enter the pit discharge. Explosives, sewage effluents, spoils, coal, and other sources can contribute pollutants to pit discharge. Pit discharge as a source is transitory in nature; that is, holding ponds would generally be moved from place to place as mining proceeds. Pit discharge to surface water will generally be done throughout mining and will move from place to place, but will be concentrated along the alluvial channels.

The relocation of spoils produces a changing chemical environment that will be a permanent potential source. Some groundwater will likely always be in contact with the lower parts of the emplaced spoils. Also, some streamflow will generally be rerouted, after mining, over the spoils along the former floodplains and percolation will occur in some areas. Holding ponds placed on the spoils would be transitory in nature. Groundwater contacting the spoils will tend to occur indefinitely in specific parts of the reclaimed areas. In any area where groundwater was present in or above the coal seam prior to mining, the spoils will generally be in contact with groundwater after mining ceases. Spoils placed below the water table have top priority among mining sources for the following reasons:

- The soil and vadose zone are bypassed, thus there is no pollutant attenuation in these zones
- Generally, materials with the highest pollution potential are placed at the bottom of the spoils, and it is this area that will be contacted by groundwater
- This source is permanent in a sense and can contribute pollutants over decades and centuries.

Another priority for mining sources would be for rerouted surface water percolating into the spoils. The extent of this problem depends largely on the chemical nature and hydraulic head ultimately established in the spoils and underlying materials and the permeability of spoils beneath the stream channel. This source will also be permanent and can contribute pollutants for many decades or centuries after mining ceases. A third priority for mining sources would be percolation of streamflow below points of pit discharge. The extent of this problem is presently poorly known due to a lack of adequate monitoring of pit discharge. Dilution due to mixing with surface water from natural runoff would limit the potential groundwater pollution.

The quality of surface water can also be adversely impacted because in some parts of the leases the groundwater contributes to surface water flow. Over the long term, substantial increases in the salinity of surface water could occur. This in turn could exert profound adverse impacts on downstream users of surface water. This factor alone necessitates continual monitoring of groundwater near the mines.

Groundwater in the coal and overlying formations is generally poor quality, and probably suitable only for industrial use (with treatment), oil field injection, or stock use. Alternative supplies are often available from deeper formations; however, the costs of drilling and pumping could be greatly increased. Similarly, potential water uses in the future that are presently unknown could be adversely impacted by lowered groundwater quality. For example, toxic substances could make the local groundwater unusable for stock use. Secondly, there is generally a downward head gradient in the sedimentary formations. Underlying aquifers utilized for drinking water, stock, industrial, and other uses could be adversely impacted.

Coal Conversion

Of the three coal conversion activities projected to be implemented in the project area, steam electric power generation, gasification, and liquification, only steam electric power generation is being implemented on a large scale. This plant is located on the Wyodak lease and most of its waste products will be disposed of in the mine pits. The primary waste will be fly ash, which will be disposed of both in ponds and as landfill. Secondary wastes, e.g., sewage effluent and sludge, will also be disposed of in ponds or as landfill.

Fly Ash Ponds—

Fly ash disposal at Wyodak in the future is presently not well known. Past disposal has been in slurry form to a pond in the North Pit. Future disposal will apparently be of two types: (1) fly ash solid landfilling in the pit, and (2) fly ash slurry pond. The fly ash slurry pond will be the depository for a number of types of wastes, many of which are liquid.

Top priority should be given to fly ash disposal in the pit at levels which will lie below groundwater level. This top priority is based on:

- The disposal is basically permanent, and pollutants can be produced for decades or centuries
- Certain trace elements may well qualify fly ash as a hazardous waste
- The soil and vadose zone are bypassed and thus pollutant attenuation in these zones will not occur
- Large volumes of fly ash will be disposed of.

Second priority should be given to the fly ash slurry pond. This priority is based on:

- The waste water disposed to this pond presents a ready source of water for leaching pollutants to the groundwater
- This source contains a variety of pollutants, including salinity from brine disposal and metals from the fly ash.

Third priority should be given to fly ash landfilled above the water table and beneath rerouted streams. This priority is based on:

- A ready source of water is available for leaching
- The fly ash may well qualify as a hazardous waste.

MUNICIPAL

The principal potential municipal sources of groundwater pollution are the landfill, sewage treatment plant, and water treatment plant. Individual wells within the City's well field are subject to damage from any of these three sources and in the long term from the mining operations. Currently not enough is known about the regional hydrogeology of the area or the long-term impacts of the mines on water to estimate what damages to the City's well field might result.

Only limited monitoring has been done on the landfill, sewage treatment plant, or water treatment plant. As a result, the following priority ranking had to be based on knowledge of what has happened under similar circumstances for the same source type at other locations. Only when more detailed information is available will it be possible to develop a ranking which has a high degree of validity.

Landfill

The City of Gillette landfill is the recipient of pollution-yielding sources ranging from domestic solid waste to a wide gamut of hazardous wastes. Because no records are kept of incoming wastes, the volume and concentrations of specific pollutants are unknown. Regulations found in the Resource Conservation and Recovery Act of 1976 will, hopefully, change this in the near future. The oily waste areas represent point sources of organic wastes as well as macroconstituents and trace contaminants. Leakage of these pollutants into the underlying coal seam may be occurring if the sealing action of sludges and sediments is not effective. In fact, seepage may have been considered as the prime method for maintaining pit capacity. The dead animal pit and the septic tank disposal area also may introduce microorganisms into shallow groundwater. The garbage trenches receive direct surface runoff during storm periods, promoting leachate generation and subsequent movement into the exposed, fractured coal seam. Some attenuation of pollutants may occur within the landfill proper, particularly microorganisms. Nevertheless, excessive levels of macroconstituents and microconstituents and organics enter with the initial leachate. The problem of groundwater contamination from pollutants at the landfill may be accentuated by the final hydraulic heads imposed by the elevation of the site and by movement through scoria and fractures.

Sewage Treatment Plant

The municipal sewage treatment plant sources consist of leaking tanks, sludge disposal pond, an oxidation pond, and flow of effluent into Donkey Creek. Leakage of raw effluent and entrained organic loads and microorganisms into the shallow groundwater system may be particularly insidious. Effluent flow into Donkey Creek will recharge over a fairly large area. Dilution of effluents may mitigate pollution to a considerable extent. Windmill wells which are still at the demonstration stage of development may be using this blended source at this time. Wastewater beyond the treatment facility will eventually be diverted to Wyodak and will then be removed largely from the list of pollutant sources (except for pipe leakage).

Water Treatment Plant

The prime source associated with the water treatment plant is brine from the desalination plant, particularly if this brine is discharged into a well. That is, pollutants are introduced directly into water-bearing strata, bypassing the entire vadose zone. Because of poor operation, however, the electrodialysis plant is generally inoperative. Seepage of brine into Stone Pile Creek may also introduce pollutants into a shallow water-table aquifer. Wastewater in the lime softening plant is not a particularly severe source because the quality is not too different from natural groundwater.

Septic Tanks

A final possible source is septic tank leach fields in the outlying trailer courts. This source may be particularly harmful to nearby privately-owned water supply wells.

There is little question that the above ranking for the major sources presented in Table 10-1 are very preliminary. This should not be surprising in view of the limited monitoring which has been done on the sources identified in Section 2. These sources probably represent only part of the problem, but do provide a starting point around which a complete monitoring program can be designed.

Data and information gaps are almost total for many of the sources identified throughout the project area. The one area of knowledge showing some degree of completeness is the geologic framework at the seven mine sites. This is not the case for the three major potential pollution sources for the Gillette area.

The next phase of the study will involve designing a monitoring program which includes the limited monitoring which has taken place thus far. The information obtained from this program will be used to verify and update the priority ranking, to identify and implement controls, and to monitor the effectiveness of these controls.

TABLE 10-1. PROJECT AREA POTENTIAL POLLUTION SOURCE PRIORITY RANKING BY MAJOR CATEGORY

Coal strip mining	Coal conversion	Municipal
1. Spoils (below water table)	1. Fly ash (below water table)	1. Hazardous wastes at landfill
2. Spoils (above water table below ponds or streams)	2. Fly ash slurry pond	2. Disposal well water treatment plant
3. Pit discharge (to streams)	3. Fly ash solids (above water table)	3. Oily waste ponds at landfill
		4. Garbage trench at landfill
		5. Sewage effluent to Donkey Creek

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APPENDIX A

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METRIC CONVERSION TABLE*

Non-metric units	Multiply by	Metric units
inch (in)	25.4	millimeters (mm)
	2.54	centimeters (cm)
feet (ft)	0.3048	meters (m)
square feet (ft^2)	0.290×10^{-2}	square meters (m^2)
yards	91.44	centimeters (cm)
square yards	0.914	square meters (m^2)
miles	1.6093	kilometers (km)
square miles	3.599	square kilometers
acres	4.047×10^{3}	square meters
	4.047×10^{-1}	hectares (ha)
gallons	3.785×10^{3}	cubic centimeters
	3.785×10^{-3}	cubic meters
cubic feet (ft^3)	3.785	liters
barrels (oil)	1.590×10^{2}	liters
acre/ft	1.108×10^{7}	liters
gallons/square foot per minute	40.74	liters/square meter per minute
cubic feet/second	3.532×10^{2}	liters/second
gallons/minute**	6.308×10^{-2}	liters/second
gallons/day	3.785	liters/day
million gallons/day	28.32	liters/second
	0.028	cubic meters/second
pounds	0.454	kilograms
	4.536×10^{-4}	tons (metric)
tons (short)	9.072×10^{2}	kilograms
	0.907	tons (metric)
pounds/acre	1.122	kilograms/hectare
parts per million (ppm)	1	milligrams per liter (mg/l)

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* English units were used in this report because of their current usage and familiarity in industry and the hydrology-related sciences.

** 1 gpm = 1.6276 afa.

Abbreviations for Units of Measure

afa	acre-feet annually
Btu	British thermal units
cc	cubic centimeters
epm	equivalents per million
g	grams
h	hour
meq	milliequivalents
mmhos/cm	micromhos per centimeter
ppm	parts per million
s	seconds